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信息技术领域

DIGEST ON  
OPTOELECTRONIC DEVICES  
AND  
SYSTEM INTEGRATION  
TECHNOLOGY

光电子器件与微电子  
光电子系统集成技术  
论文摘要集

1986 - 1990



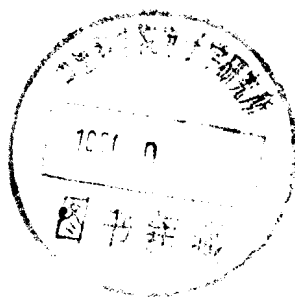
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## 内容简介

本论文摘要集主要包括以下内容: 光电子器件与微电子·光电子系统集成技术综述; 光通信系统技术; 光通信器件; 光电子集成器件; 光纤导波光学器件; 光计算算法及器件; 新型材料、器件和工艺技术。

读者对象: 从事光通信、光计算、光传感、光互连专业的科技人员, 大专院校师生。

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## 光电子器件与微电子·光电子系统集成技术论文摘要集

1986—1990

国家科委高技术计划信息领域办公室 编

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## 前 言

在本世纪大量杰出的科学技术成就中，最引人注目的是 50 年代高技术兴起。其中，信息技术方面取得的重大突破起了关键作用。1946 年电子计算机的发明，使人类的部分脑力劳动可以借助于工具来完成。1948 年半导体晶体管的发明，以及接着 1959 年以晶体管为核心的微电子芯片的诞生，使很多先进的电子系统的设计构思，可以在神奇的小硅片上实现。早在 50 年代就已迅速形成了很有特色、非常活跃、技术密集的新型半导体、计算机和通信等产业，即高技术产业。信息技术的每一步提高，都会产生超过它自身价值几倍至数十倍的效益。信息技术的研究开发和应用水准已经成为衡量一个国家发达程度的主要标志。也正因为这样，在当代高技术发展中，信息技术是领头率先的技术。

我国早在 1956 年就认识到信息技术发展的重大战略意义，做出了英明的决策，即在《一九五六年——一九六七年全国科学技术发展远景规划》中把发展半导体、计算机、自动化、电子学作为振兴科技的紧急措施来抓。由北京大学、复旦大学、南京大学、吉林大学和厦门大学等五所高校联合起来集中培养高水平创业人才，在中国科学院组建四个研究所，紧接着在工业部门设厂和建产业研究所，为我国信息技术的创业和推动国家高技术的发展奠定了良好的基础。30 多年来，在推动我国信息技术进步中，各部门领导和专家们付出了艰辛的劳动和智慧，为发展国民经济、增强国防实力和重大科技工程的完成作出了重要贡献。

1986 年 3 月中央批准了我国四位科学家提出的在高技术方面跟踪世界科技发展的重要建议，组织力量制定了针对本世纪末、下世纪初我国经济 and 科学技术持续发展有重要意义的中、长期高技术发展计划，即“八六三”计划。在对这项计划的研究战略目标征求意见和酝酿时，信息技术的跟踪又被科学家优先提名列出。考虑到它在高技术发展中的突出位置，所以信息技术与生物技术、航天技术共同列为重中之重。八六三计划中信息技术领域包含三个主题，即智能计算机系统、光电子器件与微电子·光电子系统集成技术、信息获取与处理技术。这样选取主题是立足于 20 世纪末和下世纪初的发展，预测在那个时候对科技发展和新兴产业的形成起关键作用的技术，它们也是世界各国在 90 年代实施的大型科技发展规划中重要的内容。

自八六三计划实施以来，在信息领域全体专家的共同努力下，三个主题的研究都取得了显著进展。这套（共三册）文摘集反映了部分有代表性的研究成果，大家共同的心愿是把它作为一份礼物献给八六三计划诞生五周年。这些成果表明，在中华大地上我国科学家们是能够大有作为的，只要我们勇于拼搏、积极进取，就一定能实现在未来的国际高科技发展中占有一席之地。



1991 年 1 月

## Forward

In the present century numerous outstanding accomplishments in science and technology have been made, but the rise of high technology emerged in the 50's is most spectacular. The success of high technology to a great extent attributed to the major break-throughs in information technology. The invention of computer in 1946 enabled the mankind to replace a part of brain work with tool for the first time ever in the history. Later on the semi-conductor transistor created in 1948 and the success in 1959 of building micro electronic chips with transistors as main components made it possible to have many advanced design ideas of building electronic system realized on a magic small piece of silicon chip. High technology industry was formed as early as in the 50's. It rapidly developed into very unique, active and technology intensive new industries in the field of semi-conductor, computer and communications. Since then every step forward of information technology development would generate a benefit several to dozen times higher than its own value. The level of R&D and application of information technology has therefore become a key indicator in measuring a nation of its level of development. This is why information technology plays the leading role in high technology development today.

The strategic importance of information technology was first recognized in China as early as 1956, thus a wise decision was made to include the development of semi-conductor, computer, automation, and electronics in the **1956-67 NATIONAL OUTLINE FOR DEVELOPMENT OF SCIENCE AND TECHNOLOGY** as an emergency measure aimed at revitalizing science and technology in China. Five universities including Beijing, Fudan, Nanjing, Jilin and Xiamen were then designated to coordinately train high standard personnel and four research institutes were established under the Chinese Academy of Sciences together with other new set-ups of industrial research institutes and factories under different industry sectors, which as a whole laid a good foundation for the initial development of information technology as well as development of our national high technology. Over 30 years in the past, leaders at various levels and experts have put in a lot of hard work and wisdom in the effort of developing our information technology, the result of which have made major contributions to the development of our national economy, reinforcement of our defense capability and accomplishments of key scientific and technical projects.

In March 1986 the Central Committee of the CPC adopted the important advise, which had been put forward by four scientists, aimed at keeping up with high technology development of the world. As a result, a high technology research and development program (HTRDP) was formally established in order to address the important significance of high technology for the further development of our national economy, science and tech-

nology by the end of this century and the beginning of the next. During the formulation process of the program, when comments and views were sought, scientists suggested to list information technology as a priority in the program. In consideration of the outstanding position in high technology development, it has been listed together with biotechnology and space technology as super priorities of the program. In the area of information technology of the HTRDP Program, three main topics have been identified as follows: Intelligent computer system; Optoelectric components and technology of its integration with micro electronic and optoelectronic system; and Information acquisition and processing technology. These topics were purposely selected for building reserves for our development in the end of this century and the beginning of the next based on the estimation that the technologies to be resulted from the three topics would play key roles in development of science, technology and so in newly emerging industries by then. Meanwhile, the same topics are also included in major S&T development programs as important subjects for the 90's by other countries in the world.

With joint efforts devoted by all experts working in information field, remarkable progress has been made on all three topics since implementation of the HTRDP. The papers of this proceedings (in three volumes) reflect a part of representative research accomplishments. It is our common wish to dedicate this publication to the fifth anniversary of the founding of the HTRDP . These achievements approve that our scientists do have bright prospects on the vast land of China, and we firmly believe that certainly we will be able to obtain a seat in the future competition in international development of high science and technology if we vigorously make our endeavors and keep marching forward.



Director General

Department of Basic Science and High Technology  
State Science and Technology Commission  
January, 1991

## 编写说明

一、本书是由国家科委高技术计划信息领域办公室为纪念“八六三”计划实施五周年而组织编写的。由信息领域各主题办公室汇集了有关专家在 1986~1990 年发表的重要论文摘要及其译文，供国内外有关读者参考。

二、书中 7 个部分的分类是按光电子器件与微电子·光电子系统集成技术主题项目的 7 个专题划分的，每篇文摘按其对应的课题所属的专题归类。有些文摘的归类可能不够合适，请谅解。

三、同一分类中文摘的刊登顺序按收稿时间的先后排列。

四、每篇文摘的最后一行说明该论文的首发处。

五、所有论文摘要及其译文均由作者提供，文责自负。

六、由于收取了最新发表的论文摘要，所以本书编印时间比较仓促，不足之处在所难免，敬请读者批评指正。

## Words from Editor

I. For the Fifth anniversary of implementation of 863 program, the Office of Information area of High-tech Program edited this book, consisting of abstracts of representative papers and their English versions published in 1986-90. They are compiled by each major Subject Office in the information area for the benefit of interest readers.

II. The Classification of the abstracts is based on the project administration system so it might be unperfect in the point of view of technology.

III. The abstracts in the same catalog are arranged in the sequence of time when they are acquired.

IV. The last line of each abstract indicates the original source of the paper.

V. All the abstracts and their translated versions are in such unedited form as provided by authors themselves.

VI. We would like to acknowledge everybody who gave his support for our work.

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## 一、综述 Summae

### 半导体超晶格材料和光电子器件的研究和发展

#### Development of Semiconductor Superlattice Materials and Opto-Electronic Devices

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半导体超晶格材料和以这些材料为基础的光电子器件是半导体科学和技术的一个新生长点。

超晶格材料是新一代半导体材料,它为新一代光电子器件奠定了基础。而这些新一代光电子器件正是 21 世纪光电子产业的核心。

半导体超晶格材料的研究和发展,把半导体光电子器件的研究和发展推进到一个崭新的阶段。可以预言,正如 20 世纪是电子产业的时代一样,21 世纪必定是光电子产业的年代。

Semiconductor superlattice materials and opto-electronic devices derived herefrom give rise to a new growth point of semiconductor science and technology.

Superlattice materials present a new generation of semiconductors and have laid a solid foundation for opto-electronic devices of a new generation. These devices are going to be quite the core of the opto-electronic industries during the 21st century.

Semiconductor opto-electronic devices have been forged up into a wholly new stage by the research and development of semiconductor superlattice materials.

It can be foreseen that just as the 20th century is an age of electronic industries, the 21st century will certainly be an age of optoelectronic industries.

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### 表面发射半导体激光器的进展

#### Advances of Surface-Emitting Semiconductor Lasers

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平行光电子技术急需二维半导体激光器列阵作为光源。采用表面发射半导体激光器,可制作单片集成的二维列阵。垂直腔表面发射激光器,因其可自由排列和密集封装而特别引人注目。本文评述表面发射半导体激光器及其单片集成的二维列阵的进展。

The two-dimensional semiconductor laser array used as a source is necessary for a parallel optoelectronics. A monolithic integrated two-dimensional array can be manufactured by using surface-emitting semiconductor lasers. Specially, a vertical cavity surface-emitting semiconductor laser is attractive, because of free arrangement and dense packing.

In this paper, advances of surface-emitting semiconductor lasers and monolithic integrated two-dimensional arrays composed of these devices are reviewed.

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## 准分子激光微细加工技术现状与展望

### Present Status and Future Prospect of Excimer Laser Microprocess

张玉书

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准分子激光微细加工技术是80年代发展起来的新兴加工技术。由于技术本身的强大生命力,加之超大规模集成电路和集成光学的迫切需要,特别是世界各国政府和有关学者的极大重视,使得这一技术有了长足进展,很快达到实用化程度。

本文概述了准分子激光微细加工技术在半导体工艺中的重要地位,较详细地介绍了这一技术的主要特点。重点论述了准分子激光曝光技术,CVD技术,刻蚀技术和掺杂技术等发展现状和当前主要研究课题,同时指出了今后发展的潜在活力和应用前景。

Excimer laser microprocess is a rising technology to develop from 1980s. Because of this technology itself and the urgent need of VLSI and integrated optics, especially the extreme attention of many governments and related experts all over the world, excimer laser microprocess technology has been developed greatly and has gone into practice rapidly. This paper summarized the important status of excimer laser microprocess technology in the semiconductor technique, introduced the principal characteristic of this technology which included excimer laser lithograph, CVD, etching and doping and their present status, developing and major research items in the present. Also, the potential vitality and applied prospect of this technology have been described.

本文发表在《LSI制造与测试》,第6期,1990年

## 空间光调制器技术的进展

### The Progress of Spatial Light Modulator Technologies

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空间光调制器是一类应用广泛的光电子器件。它的功能是改变一维或二维空间光分布的相位、偏振、振幅或光强,甚至也可以是波长。空间光调制器不仅可大量用于显示、自适应光学以及波长图像转换等,在光信号处理和光计算系统中更有特别重要意义。本文评述了目前空间光调制器的发展现状,并论述了该器件的功能、工作特性,以及展望了新器件、新材料的发展前景。

A review of the progress of spatial light modulator technologies is presented, including the main functions and performances, physical effects employed in SLM, trade-offs in performance parameters and recent development of new materials and new devices.

本文发表在《第五届全国集成光学学术讨论会论文集》,上海,1989年10月

## 国外光计算的进展

### The Development of Optical Computing in Foreign Countries

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本文介绍了国外光计算科研工作方面的进展,其中包括美国、欧洲、苏联在这方面的研究工作及主要研究内容。介绍了光学与电子学相比的优势所在及有关双稳态器件、光学线路、光学算法、关联存储、神经网络式光计算机、光学互连方面的进展。最后,指出了目前和长远的研究目标和对光计算机前景的估计。

This paper introduces the newly development of optical computing in foreign countries. It includes the research work in USA, European countries and USSR, the priority of optics over electronics, the optical bistable devices, the optical circuits, the optical algorithm, the associative memory or optical neural computer, and interconnections in optical computing. Finally, the author gives his comments to the aim of the research in the field of optical computing.

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## 光数字计算机的体系结构

### The Architecture of Optical Digital Computer

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本文综述了国内外迄今出现的几种人们关注的光数字计算机, 介绍了 Tse 光数字计算机、光学经典有限态数字计算机、光学顺序逻辑数字计算机、光学余数数字计算机、光学紧缩式数字计算机及符号代换数字计算机, 并指出系统结构的特点与存在的问题。

In this paper, the authors reviewed the system structure of optical digital computers, Tse optical digital computer, optical classical finite state digital computer, optical sequential logic digital computer, optical residue number digital computer, optical systolic digital computer, two dimensional pattern recognition digital computer and symbolic substitution optical digital computer have been introduced, characteristics of those systems and problems existed are also pointed out.

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## 实时光学逻辑处理

### Real Time Optical Logic Processing

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文中叙述了一实时光学逻辑处理器。零与一两种逻辑状态分别由频率不同的二光栅进行编码。它是 0 调制的延伸, 可用于多种情况下。二输出通道是分别滤出  $\pm 1$  级谱面得出的。此方案可实现 AND, NAND, OR, NOR, XOR 等 15 种逻辑运算。它可克服在逻辑运算之前对逻辑输入必须先编码且编码难于作到实时的缺点。

A real time optical logic processor is described. The logic states (zero or one) are encoded by two gratings with different frequencies. It is the extension of the Theta modulation and may be used in other cases. Two channel outputs are obtained by means of filtering the  $\pm 1$  spectrum separately. Fifteen kinds of operation including AND, NAND, OR, NOR, XOR, etc. can be performed. It can overcome the common disadvantage that the logic inputs have to be encoded before performing the logic operation and the encoding processing is difficult to carry out in real time.

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## 现代光电子学中的微小光学

### Microoptics in Modern Opto-Electronics

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微光学指用光纤、激光、微透镜和波导等元器件以实现光的发射、聚焦、传输、成像、分支、图像处理等一系列功能的微小光学系统。微小光学器件是微型化的三维组合一体化结构元器件。本文介绍了微小光学的研究内容、发展、微小光学元器件的制作工艺和在光纤通信系统、信息处理方面、光计算技术和光测量系统中的应用,最后,讨论了微小光学的发展前景。

Microoptics is a kind of microlenses system composed with optical fibers, laser devices, microlenses and waveguide components, and can be used in focusing, transmitting, imaging, branching, and pattern processing. The paper introduced the research content, development, fabrication techniques of microoptics, and the applications in fiber communications, information processing, optical computing and optical measurements. The development future of microoptics is also discussed.

本文发表在《吉林大学自然科学学报》, 1990年特刊, 第5期, 1990年

## 超大规模集成电路光互连技术的进展

### The Development of Optical Interconnect for Very Large Scale Integration

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(哈尔滨工业大学)

本文首先讨论了在超大规模集成电路中光学互连的由来, 综述了该领域的基本问题, 介绍了国内外在该领域的进展, 并对各种互连方案进行了评价。最后指出了在超大规模集成电路中光互连的发展方向。

In this paper, the reason for optical interconnect in very large scale integration is discussed. Then the essential problems in this field are discussed. And the development of the optical interconnect in VLSI is introduced and the various ways are reviewed. Finally, the direction of the development of optical interconnect in VLSI is pointed out.

本文发表在《国外激光》, 第2期, 1990年

## 全息光互连在超大规模集成电路中的应用

### Application of Holographic Optical Interconnect in Very Large Scale Integration

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本文给出了全息光互连的方法和可能遇到的问题和解决方法,给出了一点到四点的全息光互连实验结果。

所谓全息光互连就是从 VLSI 中某处的电信号驱动某一光源使之转换为光信号经 HOE 按指定的方向分束耦合到 VLSI 中的探测器上。因此在全息光互连中制作高效率高质量的 HOE 是实现光互连的关键。我们用重铬酸明胶制作了一束到四束,一束到九束,效率分别为 40% 和 30% 的全息光学元件。另外,为了有效地实现光互连,对准问题也是要解决的关键技术之一。我们采取傅里叶全息图的平移不变性和加平板垫片及光固化方法研究了这一问题。最后实现了一分立点光源到四个探测器之间全息光互连的原理实验。

The methods of holographic optical interconnect (HOI) and the problems possibly met and the solutions in HOI are discussed. And the experimental result for HOI is given.

Holographic optical interconnect is that the optical signals driven by the electric signals in VLSI are distributed in certain directions by holographic optical element (HOE) and reach at the detectors in VLSI. Therefore, making the HOE with high diffraction efficiency and high quality is one of the keys in holographic optical interconnect. Holographic optical interconnect elements were made using dichromated gelatin and their fan-out number is four and nine and the efficiencies are 40% and 30% respectively. And the alignment is another one of the main problems. We solved this problem using the Fourier hologram. The experimental result of holographic optical interconnect for clock distribution from one to four is given.

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## 二、光通信系统技术 Fibre Communication System Technology

### 光交换的现状和未来—1990 国际光交换会议评述

Photonic Switching of Today and Tomorrow—Review of 1990 International

Topic Meeting on Photonic Switching

龚小成

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1990 国际光交换会议于 1990 年 4 月 12~14 日在日本神户举行。同前二次会议相比, 光交换的概念和论证都大大发展了, 从简单、单一的开关单元和阵列发展到复杂得多的系统和线路, 包括高级信号处理作用系统, 光交换明显趋向更具控制性、更功能性和更复杂化。但是, 全光技术至少在最近的将来还不能作为光交换的主要应用, 交换和信号处理还是倾向于光和电的混合技术。因此, 可把光交换技术分成短期技术和长期技术二种类型。会议报导的器件和系统的工作很多, 包括以 III-V 族半导体量子阱材料和铌酸锂、液晶等为基础的各种光波导和集成光开关、高速光调制器、光双稳器件以及各种空分、时分和波分开关组成的光交换系统和应用等。

1990 International Topic Meeting on Photonic Switching was held on April 12~14, 1990, at Kobe, Japan. Comparing with the first two meetings, the idea and demonstration for photonic switching have evolved more rapidly, from simple, single switching elements and arrays to far more complex circuits and systems, involving sophisticated signal-processing operations. The trend is clearly towards more control, more functionality and more complex processing. It is also clear that all-optical techniques are unlikely to find significant applications for photonic switching at least not for some time to come and the prospect for optical switching and signal-handling functions is in a hybrid optical-electronic technology. Thus, photonic switching techniques can be divided into two categories: short-term techniques and long-term techniques. The papers related to devices and systems presented at the meeting are quite more, including guided-wave and integrated optical switches based on III-V Semiconductor MQW, LiNbO<sub>3</sub> and liquid Crystal, high speed optical modulator, Optical bistable devices and a lot of photonic switching systems and applications composed of space-division, time-division and wave-division switchings.

本文发表在《第四届全国纤维光学与集成光学学术交流会和第三届全国光计算技术研讨会论文集》,

即《吉林大学自然科学学报》，1990 年特刊，第 162 页

## 具有半球面共振腔的 InGaAsP / InP 面发射激光器阈值电流研究 The Threshold Current Density of InGaAsP / InP Surface Emitting Laser Diodes with Hemispherical Resonator

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面发射激光器是光信息处理的一个重要元器件。本文从理论上考虑了带有半球面的共振腔的 InGaAsP / InP 面发射激光器的阈值电流密度。计算表明，具有半球面共振腔的激光器比通常双平面共振腔的激光器有较低的阈值电流密度。当共振腔的两个反射面反射率  $R_1$ ,  $R_2$  满足  $R_1 \cdot R_2 = 0.75$  或  $0.9$  时，则该半球面共振腔的激光器有可能在室温下连续工作，其阈值电流密度分别为  $J_{th} \approx 80 \text{ kA} / \text{cm}^2$  或  $25 \text{ kA} / \text{cm}^2$ 。此时腔长为  $50 \mu\text{m}$ ，有源层厚为  $1 \mu\text{m}$ ，两面偏差角小于  $0.005 \text{ rad}$ 。

The surface emitting laser diode (SELD) is a critical component for two-dimensional laser arrays. In this paper, the theoretical calculations indicate that in the case of the cavity length  $L$  more than  $10 \mu\text{m}$ , the InGaAsP / InP SELD with hemispherical resonator is featured by having lower threshold current density  $J_{th}$  than with plane parallel resonator and will be possible in room temperature cw operation by using  $R = R_1 R_2 = 0.75$  ( $J_{th} \approx 80 \text{ kA} / \text{cm}^2$ ) or  $R = 0.9$  ( $J_{th} \approx 25 \text{ kA} / \text{cm}^2$ ,  $L = 50 \mu\text{m}$  and  $\beta < 0.005 \text{ rad}$ ).

本文发表在 USA SPIE proceeding #1418

## 脊形 InGaAsP 相位调制器

### Ridge Waveguide InGaAsP Phase Modulator

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本文报道了 InGaAsP 脊形相位调制器的初步研究结果。采用水平液相外延、常规器件工艺和湿法化学腐蚀方法，制得波导宽度  $4 \sim 8 \mu\text{m}$ 、反向击穿电压  $3 \sim 5 \text{ V}$  的相位调制器。用 Mach-Zehnder 干涉光路和  $1.52 \mu\text{m}$  激光源对器件进行测量，得到迄今最高的相位移效率，TE 和 TM 模分别为  $60^\circ / \text{V} \cdot \text{mm}$  和  $43^\circ / \text{V} \cdot \text{mm}$ 。可以认为，它和 GaAs 体系中一样，主要是应用反向电压使耗尽边传输折射指数发生巨大改变，它结合了线性电光效应、电折射效应、等离子效应和能带填充效应。

The ridge optical waveguide InGaAsP / InP phase modulators are reported. The devices with a ridge width of  $4\text{--}8\mu\text{m}$  were fabricated by liquid phase epitaxy, wet chemical etching and other conventional processes. The largest phase shifting efficiency of  $60^\circ / \text{V} \cdot \text{mm}$  and  $43^\circ / \text{V} \cdot \text{mm}$  for the TE and TM modes, respectively, ever reported for a reverse biased structure was observed at  $1.52\mu\text{m}$  wavelength.

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### 影响 InGaAsP 相位调制器相位移效率因素的研究

#### Study on Phase Shifting Efficiency of InGaAsP Phase Modulator

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由于相干光通信、光纤陀螺、光信息处理等研究工作的发展和需要，国外花费很多人力和财力研究半导体调制器，以期进行外调制。据报道，日本人已用 InGaAsP 调制器进行了  $2.4\text{Gbit/s}$   $100\text{km}$  的传输实验。

但是，至今仍很少见到对调制性能研究的系统性文章。本文在以前工作的基础上，报道了对 InGaAsP 相位调制器相位移效率的若干影响因素进行的理论分析和实验佐证。

研究表明，波导层禁带波长是影响器件相位移效率的重要因素之一。文中图示明显波导层禁带波长与器件相位移效率的关系。当波导层禁带波长接近（略小于）测试光源波长时，相位移效率很高。文中还计算了能带填充效应、电光效应等对此的影响。

On this letter, we are proposing the bandgap wavelength of waveguide layer on phase shifting efficiency of the InGaAsP phase modulator

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### InGaAsP 耗尽边传输光波导调制器的相位移效率理论计算

#### Calculation of Phase Shifting Efficiency in InGaAsP Depletion

#### Edge Translation Lightwave Modulators

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以前，调制器的大多数工作是考虑半导体的线性电光效应或自由载流子的等离子体效应，所得相位移率较低。本文基于调制器利用薄波导层的耗尽边进行光传输，并对器件加反向偏压使折射指数发生很大改变，从而产生大的位相改变的工作原理，综合分析了造成

折射率改变的各种效应。

文中首先分析计算了以下四个效应：两个是与外电场相关的线性电光效应  $\Delta n(\text{LEO})$  相电折射效应  $\Delta n(\text{ER})$ ；两个是与载流子有关的自由载流子的等离子体效应  $\Delta n(\text{PL})$  相能带填充效应  $\Delta n(\text{BF})$ 。然后，通过限制因子引入其与入射光场的作用得到有效折射率改变  $\Delta n_{\text{eff}}$ ，其中限制因子与耗尽层宽度密切相关。最终相位移效率为：

$$\Delta\Phi_N = 2\pi\Delta n_{\text{eff}} / (v_a \cdot \lambda)$$

其中： $v_a$ —器件所加反向偏压； $\lambda$ —入射光波长。

本文计算了对 TE 模和 TM 模的相位移效率，分别计算了四个效应各自产生的相位移效率以及在总效应中所占的比重，还研究了入射光波长改变以及器件掺杂浓度改变对相位移效率的影响。为高效 InGaAsP 位相调制器的研究提供了理论分析。

In this paper, we present a complete analysis of InGaAsP waveguide phase modulators based on the depletion edge translation concept. A calculation of phase shifting efficiency is reported and each one of four effects contributing to changing the refractive index is discussed.

本文发表在《第五届全国集成光学学术讨论会论文集》，上海，1989 年

### 3dB 带宽 550MHz 的 InGaAsP 相位调制器

#### InGaAsP Phase Modulator with a Bandwidth of 3dB of 550 MHz

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众所周知，采用调制器进行外调制是解决光纤通信中激光器直接调谐引起的畸变的一个重要途径。本文在以前工作的基础上，报道了 3dB 带宽为 550MHz 的 InGaAsP 相位调制器。该器件在  $1.52\mu\text{m}$  时，TE 模相位移效率为  $60^\circ / \text{Vmm}$ ，TM 模为  $43^\circ / \text{V} \cdot \text{mm}$ ，3dB 带宽为 550MHz。

该器件由水平液相外延和常规器件工艺制备。在 InP 衬底上外延生长 InGaAsP / InP 双异质结，用湿法化学腐蚀成脊形波导。器件利用薄波导层在相位传输原理综合利用能带填充效应、线性电光效应和电折射效应、等离子效应。

通过对器件等效电路的计算和理论分析，认为影响器件带宽的主要因素是器件结构引起的内部电参数、外接元件引起的杂散电容和寄生电感，以及由于阻抗不匹配引起的微波反射。在不改变器件结构的基础上，设计了阻抗匹配的微带电路，使器件测试的 3dB 带宽达到 500MHz，在 900MHz 高频调制时，测得  $13^\circ / \text{V} \cdot \text{mm}$  的相位移效率。

InGaAsP phase modulator and the dependence of modulation bandwidth of the device

are reported.  $1.5\mu\text{m}$  InGaAsP phase modulator with a bandwidth of 3dB of 550MHz and phase shifting efficiency of  $13^\circ / \text{V} \cdot \text{mm}$  at 900MHz is observed.

本文发表在“全国第五届光纤通信学术会议”

## 140Mb/s 相干光纤通信系统与中频 跟踪锁定系统

### 140Mb/s Coherent Optical Fiber Transmission System and IF Frequency-Tracking Systems

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本文报道了所研制的相干光纤通信实验系统。系统中信号激光器与本振激光器均采用 CSP 型 AlGaAs 激光二极管(HLP-1400), 工作波长为  $0.82\mu\text{m}$ , 中频线宽为 36MHz, 系统传输码率为 140Mb/s, 传输距离为 1km, 调制方式为 FSK 直接调制, 采用单滤波器后接包络检波器的解调方案, 中频放大器带宽为 260MHz, 这一系统得到了较好的解调波形和接收眼图。若采用具有更宽带宽的中频放大器, 系统性能可望进一步提高。本文还报道了所研制的中频跟踪锁定系统, 其中之一已用于上述通信实验系统中, 其中频为 920MHz, 中频频率稳定度优于 1MHz, 稳定工作时间超过 24 小时; 另一中频跟踪锁定系统的中频为 1.5GHz, 这一系统在信号功率为 -50dBm 时仍能稳定工作。

An experimental 140Mb/s coherent optical fiber transmission system is reported. In this system, the transmitter and the local oscillator are CSP-type AlGaAs laser diodes (model HLP-1400) lasing at  $0.82\mu\text{m}$ . The IF linewidth is 36MHz. The system operates at 140Mb/s with a fiber length of 1km. The transmitter is directly FSK-modulated. A single filter heterodyne receiver with an IF amplifier bandwidth of 260MHz is used. Good demodulated waveform and eye diagrams have been obtained. System performance improvement is expected when an IF amplifier with wider bandwidth is used. IF frequency-tracking systems are also reported in this paper. One of them has been used in the transmission system mentioned above with the IF frequency of 920MHz. IF frequency stability of less than 1MHz has been obtained. Over 24 hours stable operation is achieved. The other IF frequency tracking system with IF frequency of 1.5GHz is also presented. This system can work at a received signal power of -50dBm.

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## 两路频分复用相干光纤通信系统

### Two-Channel Coherent Optical Fiber FDM Transmission System

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本文报道了所研制的使用半导体激光器的两路频分复用(FDM)相干光纤通信实验系统。每路的传输码率为  $140\text{Mb/s}$ ，传输距离为  $1\text{km}$ ，使用 FSK 调制方式，采用单滤波器后接包络检波器的解调方案，工作波长为  $0.82\mu\text{m}$ ，两频道间频率间距为  $4\text{GHz}$ ，中频频率为  $750\text{MHz}$ ，中频线宽分别为  $30\text{MHz}$  和  $35\text{MHz}$ ，中频频率稳定度优于  $5\text{MHz}$ ，该系统使用一种新的稳定多激光器间频率间距的稳频方案，即使用附加低频调制将两信号激光器的频率稳定于同一 Fabry-perot 干涉腔的相邻共振峰上，同时使用快速中频跟踪系统(环路时间小于  $20\mu\text{s}$ )以消除加于信号激光器的低频调制对中频信号的影响。实验表明，这是一种简单且有效的方案，通信系统的两个频道均得到了较好的接收眼图。

An experimental two-channel coherent optical fiber FDM transmission system is reported. The system works at  $0.82\mu\text{m}$  wavelength with the transmission bit rate of  $140\text{Mb/s}$  for each channel. A  $1\text{ km}$  single-mode fiber is used. The transmitter laser diodes are directly FSK-modulated. The channel spacing between channels is  $4\text{GHz}$ . A single filter heterodyne receiver with IF frequency of  $750\text{MHz}$  is used. The measured IF linewidth for ch1 and ch2 is  $30\text{MHz}$  and  $35\text{MHz}$  respectively. IF frequency stability is better than  $5\text{MHz}$ . A new channel spacing stabilization scheme is used in this system. Low frequency modulation is applied on the transmitter laser diodes to lock them at the adjacent resonances of a Fabry-Perot cavity and a high speed IF AFC circuit with  $20\text{ us}$  response time is used to eliminate the system performance degradation due to this low frequency modulation. Good eye diagrams are obtained for the two channels.

本文发表在《第四届全国光纤通信会议的征文集》，1989 年

## 用于稳定频分复用系统中光信号频率 间距的时分复用稳频系统

### Frequency Stabilization of FDM Optical Signals by Time Division Multiplexing

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本文提出了一种新的用于稳定频分复用系统中光信号频率间距的多激光器稳频系统。在这一系统中,各激光器的频率锁定于同一 Fabry-Perot 干涉仪的不同谐振峰上,系统中采用时分复用(TDM)的方法获得各激光器的频率误差信号。这一稳频系统具有稳定度高,可稳定的频道数多,并且无需对激光器加以附加频率调制等特点。同时这一稳频系统可在 FSK 调制下稳定工作。在我们的有两个激光二极管的演示系统中,测得的以 Allan 方差表示的频率稳定度为  $10^{-10}$  数量级(10s 积分时间)。

A new frequency stabilisation scheme for FDM optical signals is proposed and demonstrated. The laser diodes are frequency-locked to comb resonances of a Fabry-perot interferometer by time division multiplexing. This technology features stable operation, high frequency stability, no disturbance to the transmitted data sequence and the capability to frequency-stabilize a large number of channels. In the demonstration experiment with two laser diodes, a frequency stability of the order of  $10^{-10}$  in the Allan variance (10s integration time) has been achieved.

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### 采用一种新的稳频方案的两路频分复用 相干光纤通信系统

#### Two-Channel Coherent Optical FDM Transmission System with a New Frequency Stabilization Scheme

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本文报道了一个采用一种新的稳频方案的两路频分复用相干光纤通信实验系统。系统中使用附加低频调制将两信号激光器的频率稳定于同一 Fabry-Perot 干涉腔的相邻共振峰上,同时使用快速中频跟踪环路以消除加于信号激光器上的低频调制对通信系统误码率的影响,系统每路的传输码率为 140Mb/s,传输距离为 1km,工作波长为  $0.82\mu\text{m}$ ,频道间距为 4GHz,使用 FSK 调制方式和单滤波器后接包络检波器的解调方式。用  $2^{15}-1$  非归零伪随机码调制,在接收信号功率为  $-41\text{dBm}$  时,系统误码率为  $10^{-9}$ ,在 4GHz 的频道间距下,未观察到邻道干扰。

A two-channel 140Mb/s coherent optical FDM transmission system with a new frequency stabilization scheme has been developed. In this scheme, low frequency modulation are applied on the transmitter laser diodes to lock them at the resonances of a Fabry-Perot interferometer and a high speed IF AFC circuit is used to eliminate the system performance degradation due to this low frequency modulation. The system works at  $0.82\mu\text{m}$  wave-

length with the fiber length of 1 km and the channel spacing of 4GHz. The transmitter laser diodes are FSK-modulated with two independent  $2^{15}-1$  NRZ-coded PN patterns. A single filter heterodyne receiver is used. The measured BER is  $10^{-9}$  for the received signal power of -41dBm and no crosstalk between channels is observed with the channel spacing of 4.0GHz.

本文发表在 Electronics Letters, Vol.26, No.5, 1990

## 140Mb/s 两路频分复用相干光纤通信 实验系统

### Two-Channel Coherent Optical FSK Transmission

#### Experiment at 140Mb/s

江 泉 吴德明 谢麟振

(北京大学无线电电子学系)

本文报道了所研制的两路频分复用相干光纤通信实验系统。每路的传输码率为 140Mb/s, 传输距离为 1km, 两信号激光器的频率锁定于同一 Fabry-perot 干涉仪的相邻共振峰上, 频道间距为 4GHz, 系统工作波长为  $0.82\mu\text{m}$ , 使用 FSK 调制方式和单滤波器后接包络检波器的解调方式。中频频率为 750MHz, 中频放大器的带宽和增益分别为 500 MHz 和 66dB, 用频率计数器测得的中频频率漂移优于  $\pm 3\text{MHz}$ 。系统基带滤波器的带宽为 90MHz。系统中使用  $2^{15}-1$  非归零伪随机码调制, 在误码率为  $10^{-9}$  时, 系统接收灵敏度为 -42.5dBm, 测得的系统最佳误码率在  $10^{-12}$  量级。在 4GHz 的频道间距下, 未观察到邻道干扰。

In this paper, we report a two-channel coherent optical FSK transmission experiment at 140Mb/s. In this experiment, transmitter laser diodes are frequency-locked to the adjacent resonances of a Fabry-Perot interferometer by applying low frequency modulation on them and a high speed IF AFC circuit is used to eliminate the system performance degradation due to this low frequency modulation. The system works at  $0.82\mu\text{m}$  wavelength with the fiber length of 1 km and the channel spacing of 4GHz. The transmitter laser diodes are FSK-modulated with two independent  $2^{15}-1$  NRZ-coded PN patterns. A single filter heterodyne receiver with the IF frequency of 750MHz is used. The IF amplifier has a power gain of 66 dB and a bandwidth of 500MHz. The IF frequency drift measured with a frequency counter is less than 3MHz. The system sensitivity is -42.5dBm at the BER of  $10^{-9}$ , and the best result obtained for the BER is in the order of  $10^{-12}$ . No crosstalk between channels is observed with the channel spacing of 4.0GHz.

## 用电负反馈方法压低半导体激光器的 FM 噪声的新实验结果

### New Experimental Results of Linewidth Narrowing and FM Noise Reduction of Semiconductor Laser Diodes by Negative Electrical Feedback

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本文报道了使用快速电负反馈压低半导体激光器的调频 (FM) 噪声的新实验结果。在快速电负反馈方法中所特有的对压制激光器 FM 噪声有着重大消极影响的正反馈峰, 已通过对反馈环路的合理设计(包括引入滤波器)将其基本消除, 并获得了在 15MHz 以下频率范围内有压低激光器 FM 噪声的效果, 其最大压低量为 10dB 左右。实验中所使用的激光器的型号为 HLP-1400, 工作于 1.8 倍阈值, 输出功率为 15mW, 其激射线宽为 18MHz, 这样, 10dB 左右的压低 FM 噪声的效果, 相当于将激光器的线宽压窄了一个量级, 即压窄到 MHz 量级。

本实验系统中引入了一个匹配滤波器, 其 3dB 带宽为 3MHz; 其增益衰减速率为每倍频程数 6dB (6dB / OCT)。由于精心的电路、光路设计, 在未引入滤波器前, 反馈环路的正反馈峰已在 40MHz 处。这样, 这一滤波器的引入将完全可以消除电负反馈压窄激光器线宽技术中的固有正反馈峰。

New experimental results about linewidth narrowing and FM noise reduction of semiconductor laser diodes by negative electrical feedback (NEFB) have been reported. The positive feedback peaks existed in NEFB which can make great negative impact on linewidth narrowing have been eliminated by careful loop designing (including adding the filter). The FM noise of the semiconductor laser has been reduced by 10dB (maximum) at the frequency region lower than 15 MHz. The model of the laser diode used in the experiment is HLP-1400, and it operates at 1.8 I<sub>th</sub>, with an outpower of 15mW and a linewidth of 18MHz. Since the linewidth narrowing factor of 10 can be expected when the FM noise suppression of the laser diode is 10dB, So the linewidth of the laser diode in this NEFB experiment can be as narrow as about 1-2MHz.

The parameters of the matched filter used in the experiment are following its 3dB bandwidth is 3MHz and the gain decay rate is 6dB / OCT. Due to the careful designing of the electrical circuit and optical path, the loop time is 25ns, and the positive feedback peak in the experiment is at 40 MHz when the filter is not added. Therefore this matched filter can completely eliminate the positive feedback peak.

本文发表在“光电子器件及集成技术会议”，1989年3月

## 一个新的稳定频分复用光源的 时分稳频系统

### A New Scheme for Stabilizing Laser Frequencies in FDM COFC Systems by TDM

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本文报道了一种新的锁定多路频分复用相干光纤通信系统中激光器频率间距的时分稳频系统。我们在 F-P 腔上加阶梯波，使 F-P 腔在一个自由光谱区的频率范围内周期性地产生多个等间距的共振峰，多个激光器的光信号分时通过 F-P 腔，阶梯波就是时分复用中的光开关信号。稳频时，我们不对外腔激光器进行低频调制，而对 F-P 腔进行正弦调制，所产生的频率误差信号反馈控制外腔激光器的 PZT，从而将多个外腔激光器的频率分别锁定于 F-P 腔的上述多个等间距的谐振峰上。该时分稳频系统的优点是，立意新、简单易行、稳定路数多、而且对传输的数据序列没有任何干扰。

Here is a new method for channel spacing stabilization used in densely spacing FDM transmission systems. A periodic step wave signal is applied on a F-P cavity to create periodically a number of equally spaced resonance peaks within one FSR frequency range, to which the transmitter lasers are frequency-locked in a given order set by an electronic switch which is synchronous with the step wave and implements the Time Division Multiplexing. Moreover, the additional modulation on the transmitter lasers is avoided, consequently there is no disturbance to the transmitted data sequence.

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### 三、光通信器件

## Fibre Communication Device

#### GaAs-GaAlAs 行波激光放大器的特性

#### The Properties of a GaAs-GaAlAs Traveling-Wave Laser Amplifier

张月清 秦志新 武胜利 王立军 李殿英

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GaAs-GaAlAs DH 半导体激光器的两个谐振腔镜的反射率用溅射 SiN 的方法使其减至  $1 \times 10^{-3}$ 。测量了行波激光放大器的增益。最高增益为 25dB。测量了增益随注入电流的变化。所测频率带宽表明行波激光放大器比其它类型半导体激光放大器有显著的优越性。

The reflectivity of the cavity mirrors of a GaAs-GaAlAs DH semiconductor laser are reduced to  $1 \times 10^{-3}$  by sputtering a film SiN. The gain of traveling-wave laser amplifier is measured. The highest gain is about 25 dB. The dependence of gain on the injection current is measured. The measured frequency bandwidth shows the great advantage over other type of semiconductor laser amplifiers.

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#### 腔面倾斜的 GaAs-GaAlAs 行波型激光放大器

#### GaAs-GaAlAs Traveling-Wave Type Laser Amplifier with Tilted Facets

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用质子轰击法制成腔面具有不同倾斜角的 GaAs-GaAlAs 行波型激光放大器。测量了该器件的若干特性。具有光纤耦合的行波激光放大器测得的最大单程增益为 27.8dB。

GaAs-GaAlAs traveling-wave type laser amplifiers with different tilted angles facets are defined by proton-bombardment. Some characters are measured. Maximum single-pass gain of 27.8dB are attained with optical fiber coupling system.

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### 行波型半导体激光放大器的增益开关特性

#### Gain-Switched Property of Traveling-Wave Type Semiconductor Laser Amplifier

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在非稳定条件下行波型激光放大器显示出它的增益开关特性。计算了它的增益系数。它的增益系数随信号光强的时间积分值而变。行波型激光放大器可以用作为一光闸门, 其时间分辨率小于 100ps。

Traveling-wave type laser amplifier shows its gainswitched property under unstable condition. Its gain coefficients are deduced theoretically. The gain coefficients are changing with the integral of optical signal intensity over time. TW type laser amplifier can be used as an optical gate with a time resolution better than 100 picosecond.

本文发表在“International Topical Meeting on Solid State / Semiconductor Lasers”, Proceeding Volume 2 of 2, pp.1333-1335, Beijing, June, 1990

### 一种测量 GaAs-GaAlAs 行波激光放大器增益特性的实验方法

#### A New Experimental Method for Measuring Gain Properties of GaAs-GaAlAs

#### Traveling-Wave Laser Amplifier

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本文报导了一种测量光耦合效率  $\eta$  的新实验方法。这个方法是建立于 p-n 结短路光电流原理上的。本文推导出适合于行波激光放大器的光耦合效率的公式。短路光电流用一检流计测量, 利用公式获得光耦合效率的实验值。利用实验所测光耦合效率, 测量了行波激光放大器的增益随注入电流变化的规律, 其结果和实验符合。另外本文还介绍了在脉冲注入电流条件下测行波激光放大器增益的实验方法。

In this paper a new method for measuring  $\eta$  has been reported. This method is based

on the principle of short optical current of p-n junction.

Suppose  $P_{in}$  (optical power) is incident on one of the cavity mirrors. If the incident photon energy is  $h\nu \approx E_g$  (the energy gap of semiconductor of active region), free carriers—electrons and holes—are excited. These free electrons and holes flow in opposite directions under the action of built-in field in p-n junction. The short optical current is composed of these free electrons and holes. Hence the short current can be used to measure the input optical power and to measure  $\eta$ . The formulas of optical coupling efficiency  $\eta$  for traveling-wave laser amplifier are deduced. The short optical currents are measured by a galvanometer. Then the optical coupling efficiency  $\eta$  are calculated by the formulas. Using the experimental data of  $\eta$ , the dependence of gain of traveling-wave semiconductor laser amplifier on injection current is obtained. It is agree with theory. Besides, the measuring method of gain of traveling-wave semiconductor laser amplifier under pulse injection current condition is also given.

本文发表在《发光学报》，第 10 卷，第 1 期，1989 年

### 1.5 $\mu$ m InGaAsP / InP 脊型波导分布反馈激光器

#### 1.5 $\mu$ m InGaAsP / InP Ridge Waveguide DFB Laser

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马朝华 王丽明 吕 卉 高俊华 高洪海

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用两次液相外延制备了 InGaAsP / InP 脊型波导分布反馈激光器，室温下无扭折直流光功率超过 6mW，阈值电流为 34mA，单面外微分量效率高达 33%。在室温附近的稳定单纵模工作温度范围超过 43℃，波长温度系数为 0.09nm / K，在 1.6mW 输出光功率下的静态线宽为 60MHz，在 1GHz 正弦调制下仍为单纵模输出。

Ridge-Waveguide (RW) DFB Laser emitting at 1.52 $\mu$ m grown by two-step LPE has been demonstrated. The output power more than 6mW without kink was obtained in CW operation at the room temperature. The CW threshold current of 34mA and differential quantum efficiency of 33 percent per facet were achieved at the room temperature. The stable single longitudinal mode operation was realized in the temperatures ranging from 2 to 43℃, The static spectral linewidth was 60MHz at 1.6mW output power. The modulation characteristic was measured up to 1GHz with the modulation depth of 50%.

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## 非线性变周期全息光栅的制作

### The Fabrication Method of Holographic Chirped Gratings

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叙述一种用发散光束来制作变周期光栅的方法,简单的系统保证了两束形成全息干涉的光强相等。这一点对获得高反衬结构的光栅图形是重要的。在显影过程中用 He-Ne 激光作为衍射效率的在位监控。

Gratings with variable periods (chirped gratings) have been fabricated by recording the interference pattern of a converging beam. The simple system ensures that two beams forming the holographic grating have equal intensities. This is crucial for obtaining high aspect-ratio structures. We use a He-Ne laser beam for observing the efficiency of diffraction grating as development proceeds.

本文发表在《高速摄影与光子学》,第 19 卷,第 2 期

## 电光调谐窄带高反 Bragg 反射器

### Electro-Optical Tunable Narrow Bandwidth High Reflectivity Bragg Reflector

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本文探讨一种扩钛  $\text{LiNbO}_3$  波导电光调谐窄带高反 Bragg 反射器的新方案,对晶向选择,最大调谐范围,带宽作了分析,指出可能制作出带宽小于  $0.07\text{nm}$ ,调谐范围大于  $0.75\text{nm}$  的反射器。与交叉电极方案相比较,我们发现带宽的减小是以调谐范围的缩小为代价的,二者的比值约为常数。

A new scheme of electro-optical tunable narrow bandwidth high reflectivity Bragg reflector on Ti diffused  $\text{LiNbO}_3$  waveguide is investigated, emphasised on the crystal direction choosing, maximal tuning range and bandwidth. We show it's possible to fabricate a  $0.07\text{nm}$  bandwidth Bragg reflector with more than  $0.75\text{nm}$  tunable range. Compared with interdigital electrode scheme, we find that the reduction of the bandwidth is at the cost of the reduction of tuning range, their ratio is nearly a constant.

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## 选择性反射器外腔半导体激光器调谐特性分析

### On the Tuning Properties of Frequency Selective Reflector

#### Extended Cavity Semiconductor Lasers

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本文介绍选择性反射器外腔激光器调谐特性的理论分析。结果表明: 1) 调谐范围的极限由增益条件决定, 而调谐曲线形状由相位条件决定; 2) 增加反射器的反射率, 提高激光器与外腔的耦合效率减小外腔的损耗, 内腔反射率和选择性反射器带宽都对改善调谐特性有益; 3) 当反馈量较小时, 内腔的反射率的减小应以不明显增大阈值电流为佳。

We present results of a theoretical analysis of tuning properties of frequency selective reflector extended cavity lasers. We found that 1) the extreme tuning range is mainly determined by the amplitude condition; 2) increasing the reflectivity and decreasing the loss of the external cavity, increasing the coupling efficiency and decreasing the laser facet reflectivity are all helpful to improve the tuning properties; 3) if the feedback is weak, the reflectivity of the facet faced on external cavity must be AR coated to the point where the threshold current do not increase considerably.

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## 环型光纤延迟零差光谱分析仪

### Time-Delayed Optic Fiber Ring Homodyne Linewidth Analyzer

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本文介绍一种环型光纤延迟零差光谱分析仪, 用熔结式光纤方向耦合器代替分束镜, 与一根长 3km 单模光纤相连接构成了环型延迟器。最大光谱分辨率和最大分析频宽分别为 50kHz 和 20MHz, 灵敏度小于 -40dBm, 由于采用了全光纤形式, 可以去掉所有的块状光学部件, 所以比外差法结构更加紧凑, 机械稳定性更好。整个分析仪的损耗极小, 因而用偏置简单的 PIN-FET 接收机代替 APD 探测器。

We present a time-delayed optic fiber ring homodyne linewidth analyzer. The time-delayed ring is composed of a 3km monomode fiber and a fused optical directional coupler which replaces the beam splitter in conventional system. The maximal analysis resolution and spectrum analysis range are 50kHz and 20MHz respectively, with sensitivity less than -40dBm. Due to full optic fiber structure, conventional block optical devices are all

removed which make the analyzer more compact and stable as compared with heterodyne analyzer. The optical loss of overall analyzer is also very small, so instead of APD detector, a simple PIN-FET receiver is used.

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### 非平面衬底上制备光栅

#### Fabrication of Gratings on Non-Planer Substrate

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我们采用无掩膜直接光电化学腐蚀法成功地在沟宽  $6\mu\text{m}$ ，沟深  $0.5\sim 1\mu\text{m}$ ，沟长  $200\mu\text{m}\sim 1\text{cm}$  的 n-Inp 衬底沟槽上制作了二级光栅，光栅周期为  $460\text{nm}$ ，深为  $50\text{nm}$ ，已用于 InGaAspDFB 激光器的制备。这一独特的微区非平面光栅加工工艺稳定，十分适用于集成光器件的制备。

we applied a maskless direct photo electro chemical etched technique to produce successfully periodic gratings on n-Inp substrate channel with width of  $b\mu\text{m}$ , depth of  $0.5\sim 1\mu\text{m}$ , length of  $200\mu\text{m}\sim 1\text{cm}$ . The periodic corrugating are trigono-angular shape with period of  $460\text{nm}$  and depth of  $50\text{nm}$ . This special technique of fabricating micro-area non-plane surface gratings has good stability and is suitable for manufacture integrated optical devices.

本文发表在《1989 年第五届全国集成光学年会文集》，第 156 页

### n-Inp 光栅制备的新技术——无掩膜光电化学腐蚀法

#### New Technique of Fabricating Gratings on n-Inp Maskless

#### Photo-Electro-Chemical Etched Method

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本文报导了一种制备光栅的新方法——无掩膜直接光电化学腐蚀化。已成功地获得大面积、线条均匀、空间频率  $> 1000\text{mm}^{-1}$ ，深为  $70\text{nm}$  的 Inp 表面波纹光栅。此法比起普通的全息曝光光刻胶、湿化学腐蚀工艺具有工艺简单，重复性好的特点，因此是 DFB 或 DBR 激光器，以及光集成器件制备的实用工艺。

In this paper we reported a new technique of fabricating surface gratings which is called maskless direct photoelectro chemical etched method. A large area, uniform periodic surface corrugations with space frequency of more than  $1000\text{mm}^{-1}$  and depth of  $70\text{nm}$  have been produced successfully. Comparing with the general hologram exposure, photoresist mask and wet chemical etched technique, this method has a good advantage such as simple technology, easy operation, good repeatability. Therefore, the technique is practical and suitable for manufacture DFB or DBR Lasers and integrated optical devices.

本文发表在《1989年光电子器件与集成技术年会论文集》，第31~33页

### 输出大于 130mW 的 GaAlAs / GaAs 锁相列阵激光器及其特性测试

#### A Phase-Locked GaAlAs / GaAs Laser Array with More Than 130mW Output and

#### Its Characteristic Measurement

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本文报导一种结构和工艺较为简单的锁相列阵激光器。列阵由十个激光器组成，采用液相外延生长四层平面的双异质结，顶层为 N 型，用扩 Zn 工艺形成侧向为反向 P-N 结限制的条形结构。典型器件阈值电流为  $170\text{mA}$ ，输出功率达  $130\text{mW}$ （工作电流为  $530\text{mA}$ ，功率-电流曲线保持良好线性。斜率效率为  $0.36\text{mW}/\text{mA}$ ，单面微分量子效率为  $26\%$ 。器件典型远场分布为双瓣光束，两瓣间角距为  $3.5^\circ$ ，主瓣半功率全宽为  $2^\circ$ 。在垂直于 P-N 结方向束宽为  $37^\circ$ 。部分器件呈现单瓣光束。这表明激光器之间实现了相位锁定。实验中还测量了器件的光谱和温度特性，特征温度大于  $133\text{K}$ 。

A phase-locked laser array, fabricated by using a simple structure and technology, is presented in this paper. The array consists of ten lasers, which are made by Zn diffusion on the top N-type layer of the four LPE-grown DH wafer. The lateral confinement is provided by reverse P-N junctions. The typical threshold current of the devices is  $170\text{mA}$ . Output power up to  $130\text{mW}$  (at  $530\text{mA}$  operating current) is obtained with a linear L-I curve. The slope efficiency is  $0.36\text{mW}/\text{mA}$ , and the differential quantum efficiency of one facet is  $26\%$ . The typical farfield is two-lobe beam. The spacing between the lobes is  $3.5^\circ$ , and the beam-width of the main lobe is  $2^\circ$ . The beam-width in the direction perpendicular to P-N junction is  $37^\circ$ . Far-field with a single lobe can be observed for some arrays. It shows that phase-locking occurs among the lasers. The spectra and thermal characteristics of the devices were also measured and  $T_0$  was obtained to be more than  $133\text{k}$ .

本文发表在《1989 光电子器件与集成技术年会》

### **1.3 $\mu$ m DCPBH 激光器的千兆赫直接调制** **GHz Direct Modulation of 1.3 $\mu$ m DCPBH Lasers**

张位在 方祖捷

(中国科学院上海光学精密机械研究所)

本文报导了 1.3 $\mu$ m 激光器的射频直接调制实验。获得了频率为 1GHz, 脉宽小于 120ps, 调制度为 80% 的实验结果。对 DCPBH 激光器的结构对调制特性的影响进行了讨论。

RF direct modulations of 1.3 $\mu$ m DCPBH lasers were studied experimentally. 1GHz modulation frequency. 120ps pulse with and 80% modulation depth were obtained. Influences of laser structure on modulation characteristics were also discussed.

本文发表在《光通信技术》, 第 4 期, 1989 年

### **直接调制获得 1.3 $\mu$ m 半导体激光超短脉冲** **Ultra-Short Pulses of 1.3 $\mu$ m Semiconductor Lasers by Direct Modulation**

张位在 张影华 谢黄海 张莲英 方祖捷

(中国科学院上海光学精密机械研究所)

本文报导采用梳状波发生器直接调制的 1.3 $\mu$ m DCPBH 激光器以及脉宽的二次谐波相关测量系统。获得了重复频率为 1GHz, 最短脉宽为 17ps 的光脉冲; 给出了脉宽和峰值功率随偏置电流变化的关系。表明当偏置在阈值附近时, 可获得最短脉宽和最高峰值功率。

1.3 $\mu$ m optical pulses with repetition frequency of 1GHz and pulse width of 17ps were obtained by using a comb generator and direct modulation of DCPBH lasers. Experiments on SHG correlation system are also described. It is shown that the shortest pulse and the highest peak power are obtained when the laser diode is biased near threshold.

本文发表在《中国激光》, 第 2 期, 1991 年

### **多模光纤复合腔 1.3 $\mu$ m InGaAsP 激光器产生皮秒超短光脉冲**

## Picosecond Optical Pulses Generation from a $1.3\mu\text{m}$ InGaAsP Laser with a

### Multimode Fiber Extended Resonator

谢黄海 张位在 张莲英 方祖捷

(中国科学院上海光学精密机械研究所)

本文报导采用多模光纤外腔形式, 从  $1.3\mu\text{m}$ InGaAsP 激光器中产生重复频率为 1GHz 的 18.1ps 超短光脉冲的实验结果, 并对实验结果进行了一些讨论。

18.1ps optical pulses with a repetition rate of 1GHz were obtained from a  $1.3\mu\text{m}$  InGaAsP laser with a multimode fiber extended resonator. Discussions about the experimental results are presented.

本文发表在《中国激光》

### $1.3\mu\text{m}$ 波长单模激光器实用化组件的研制

#### Development of a $1.3\mu\text{m}$ Single Mode Laser Module

张莲英 谢黄海 方祖捷

(中国科学院上海光学精密机械研究所)

本文报导我们研制的单模半导体激光器组件。这种器件利用锥形半球端微透镜与单模及多模光纤耦合, 提高了耦合效率。使用国产元件制成了具有光控、温控、尾纤输出功率高的实用化组件。测试结果表明, 其基本性能达到了光通信实用化的要求。

A single-mode semiconductor laser module was developed. The coupling efficiency between the laser diode and the fiber was greatly increased by using a tapered hemispherical end. The module consists of light control, temperature control and fiber pigtail outlet, and it was fabricated by using domestic elements. The measurement results show that its basic performance meets requirements of practical optical fiber communication.

本文发表在《1989 光电子器件与集成技术年会论文集》

### 吉赫直接调制产生的 16ps $1.5\mu\text{m}$ 激光脉冲

#### 16ps Pulses of a $1.5\mu\text{m}$ Laser Generated by GHz Direct Modulation

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我们利用微波标准信号发生器, 通过可变衰减器及由阶跃二极管和微波传输线组成的梳状波发生器, 获得底宽为 200ps, 重复频率为 1GHz 超短电脉冲。通过 50 $\Omega$  T 型网络把上述电脉冲和直流偏置加到激光器上。所用的 1.5 $\mu$ m DCPBH 激光器由本所研制, 阈值电流 75mA。光脉冲宽度用二次谐波相关接收技术测量。按高斯波形计算, 当直流偏置为 75mA、脉冲电流峰值为 200mA 时, 脉宽为 16ps。激光峰值功率为 156mW。观察激光光谱及与之比较的同一器件的直流光谱, 可以看出在高频直接调制下谱线加宽。本文报导的超短光脉冲现象可以用增益开关机理加以解释。

Pulses with 200ps bottom width and 1GHz repetition rate from a comb generator consisting of a step diode and a microwave line, driven by a RF source with an attenuator, were applied to a 1.5 $\mu$ m DCPBH laser together with a dc bias through a 50 $\Omega$  T-type network. The laser was made in SIOM and its threshold was 75mA. The pulse width was measured by using SHG auto-correlation method. According to Gaussian shape, the pulse width was figured out to be 16ps at 75mA dc bias and 200mA pulse current. The peak output was 156mW. Spectra of the laser were measured at dc bias and at modulation respectively. A spectral line broadening can be observed at high frequency modulation. The ultra-short pulse phenomenon can be explained by gain switching.

本文发表在“第十届全国激光学术会议”, 呼和浩特, 1990 年 7 月, 与《激光与红外》, 第 4 期, 1990 年

### 1.3 $\mu$ m 低阈值掩埋新月型 InP-InGaAsP 激光器 InGaAsP / InP Buried Crescent Laser Emitting at 1.3 $\mu$ m with Low Threshold Current

肖建伟 苗忠礼 衣茂斌  
薄报学 马玉珍 高鼎三  
(吉林大学电子科学系)

我们用两步液相外延技术制成 1.3 $\mu$ m InGaAsP / InP 掩埋新月型激光器。典型的和最小的阈值电流分别是 20 和 11mA。在 3 倍阈值下仍可稳定的基横模工作。个别器件直到 7mW 仍可维持单纵模输出。

1.3 $\mu$ m InGaAsP / InP buried crescent laser have been fabricated by two step LPE growth processes. The typical and the minimum threshold current are 20 and 11mA, respectively, stable fundamental transverse mode operation can be obtained at three times or threshold current. Several device were lasing with single longitudinal mode under 7mW.

本文发表在《吉林大学自然科学学报》，1987年第4期

**1.3 $\mu$ m InP / InGaAsP 多层限制掩埋新月型激光器**  
**InP / InGaAsP Multi-Blocking Layer Buried Crescent Laser Emitting at**  
**1.3**

**$\mu$ m with Low Threshold Current**  
肖建伟 薄报学 衣茂斌 马玉珍 高鼎三  
(吉林大学电子科学系)

我们采用二次液相外延技术研制出 1.3 $\mu$ m 低阈值、稳定基横模激射多层限制掩埋新月型 InP / InGaAsP 激光器。典型室温连续工作阈值电流 20mA，最低值 10mA。在 3~5 倍阈值工作电流下仍可以稳定的基横模激射，单面微分量子效率为 20~30%。

1.3 $\mu$ m InP / InGaAsP multi-blocking layer buried crescent lasers have been fabricated by two step LPE growth processes. The typical and the minimum CW threshold currents are 20mA and 10mA, respectively. Stable fundamental transverse mode operation has been obtained at three to five times of the threshold current. The differential quantum efficiency per facet is about 20-30%.

本文发表在《半导体学报》，第9卷，第6期，1988年11月

**低阈值稳定基横模 1.3 $\mu$ m InGaAsP / InP 掩埋新月型激光器**  
**1.3 $\mu$ m InGaAsP / InP Buried Crescent Semiconductor Lasers with Low**  
**Threshold**

**Current and Stable Fundamental Transverse Mode**  
肖建伟 衣茂斌 薄报学 苗忠礼 马玉珍 高鼎三  
(吉林大学电子科学系)

采用二次液相外延技术研制 1.3 $\mu$ m InGaAsP / InP 掩埋新月型激光器，测试结果表明，典型室温连续工作电流为 20mA，最低 10mA。在 3~5 倍阈值工作电流下仍能稳定的基横模激射。

1.3 $\mu$ m InGaAsP / InP buried crescent lasers were fabricated in our laboratory. The typical and the lowest threshold currents of the devices are 20mA and 10mA respectively. These lasers could maintain stable fundamental transverse mode operation to 5 times of



threshold current.

本文发表在《吉林大学自然科学学报》，1989年第4期

**用  $1.3\mu\text{m}$  半导体激光器直接调制产生 2.1GHz 超短光脉冲**  
**2.1GHz Picosecond Optical Pulse Generation from Semiconductor Laser**  
**at**

**$1.3\mu\text{m}$  Wavelength by Direct Modulation**

贾刚 孙伟 衣茂斌 高鼎三

(吉林大学电子科学系)

报道了直接调制 InGaAsP 半导体激光器获得重复率为 2.1GHz、脉宽为 25~60ps 的超短光脉冲。

The generation of picosecond optical pulses by direct modulation of InGaAsP diode laser is reported. Pulse width of 25–60ps is achieved at repetition frequency of 2.1GHz.

本文发表在《红外研究》，第九卷，第五期，1990年10月

**$1.3\mu\text{m}$  波长 InGaAsP 激光器产生的亚微微秒光脉冲的干涉自相关测量**  
**Interferometric Autocorrelation Measurements of Subpicosecond Optical**  
**Pulses from  $1.3\mu\text{m}$  Wavelength InGaAsP Diode Laser**

贾刚 孙伟 衣茂斌 高鼎三

(吉林大学电子科学系)

建立了用步进电机扫描的干涉自相关仪。测量了用  $1.3\mu\text{m}$  波长 InGaAsP 激光器产生的 0.45ps 的光脉冲。根据干涉自相关函数判定该脉冲是没有调制偏移的双曲正割型光脉冲。

An Interferometric autocorrelator scanning with step electric motor has been set up. Optical pulses with 0.45ps FWHM from a  $1.3\mu\text{m}$  wavelength InGaAsP diode laser have been measured. According to the interferometric autocorrelation results, the pulses are unchirped hyperbolic secant pulses.

本文发表在《半导体学报》，第11卷，第9期，1990年9月

## InP-InGaAsP BC 激光器高速调制特性的研究

### Characterization of High Speed Modulation of an InP-InGaAsP Semiconductor Laser

肖建伟 衣茂斌 高鼎三  
(吉林大学电子科学系)

本文从理论和实验上研究了 InP / InGaAsP 多重限制 BC 激光器的高速调制特性。这种 BC 激光器的调制频率带宽从理论上估计是 5.8GHz, 在实验上受我们所用的光电二极管的频率响应的限制, 为 3GHz。

The high speed modulation performance of an InP / InGaAsP multi-blocking BC laser have been theoretically and experimentally investigated. The modulation frequency bandwidth of the BC lasers we fabricated are theoretically expected to be 5.8GHz, and experimentally limited to 3GHz by frequency response of the photodiode used.

本文发表在“89' 光电子器件与集成技术年会”

## 用 1.3 $\mu$ mGaInAsP / InP 激光器产生的超短光脉冲及其强度自相关测量

### Ultrashort Optical Pulses from 1.3 $\mu$ m GaInAsP / InP Lasers and Intensity Autocorrelation Measurement

贾刚 孙伟 衣茂斌 高鼎三  
(吉林大学电子科学系)

我们建立了测量 1.3 $\mu$ mGaInAsP / InP 激光器产生的超短光脉冲的强度自相关系统。在无偏置电流条件下用窄的电脉冲驱动 1.3 $\mu$ mGaInAsP / InP 多层限制掩埋新月型激光器, 获得了 FWHM 为 15ps 的超短光脉冲。用直接的正弦电流调制获得 FWHM 为 25~60ps 的超短光脉冲, 并观察到 0.45psFWHM 的被动锁模光脉冲。

Intensity autocorrelation system for the measurement of ultrashort optical pulses from 1.3 $\mu$ m wavelength GaInAsP / InP lasers has been set up. Ultrashort optical pulses with 15ps FWHM are obtained from 1.3 $\mu$ m wavelength GaInAsP / InP multi-blocking layer buried crescent lasers driven by narrow electrical pulse without bias current. Ultrashort pulse with 25~60ps FWHM are obtained by direct current modulation, passive mode-locking pulses with 0.45ps FWHM are observed.

本文发表在“89' 光电子器件与集成技术年会”

## 高速调制半导体激光器的研究

### Semiconductor Laser for High Speed Modulation

肖建伟 衣茂斌 高鼎三

(吉林大学电子科学系)

我们讨论了影响半导体激光器高速调制的某些因素,成功地设计并制造了一种 InP/InGaAsP 多层限制掩埋新月型激光器。CW 阈电流在 10 与 20mA 之间,最小阈电流是 8.5mA。P<sub>max</sub> 大于 30mW。室温下的寿命时间大于十万小时,调制带宽大于 3GHz。用直接正弦电流调制产生的光脉冲,FWHM 约 25ps,重复率为 2.1GHz。

The effects of some factors on high speed modulation of a semiconductor laser have been discussed. We have successfully designed and fabricated an InP/InGaAsP multi-blocking layer buried crescent laser. The CW threshold current ranged between 10 and 20mA, and the minimum threshold current was 8.5mA. P<sub>max</sub> > 30mW. The lifetime at room temperature > 10<sup>5</sup>h. The modulation bandwidth > 3GHz. The generation of picosecond optical pulse train by direct modulation of the BC-InGaAsP diode laser, with FWHM of 25ps and repetition rate of 2.1GHz, have been achieved.

本文发表在“第六届全国化合物半导体和微波光电器件学术会议”

## 光纤通信用 PLZT 光开关

### PLZT Electro-Optic Switch

#### for Fibre-Optic Communication

曾庆济\* 杜敏\* 郑鑫森\*\*

(\*上海交通大学、\*\*上海硅酸盐研究所)

本文作者设计制作了一个利用 PLZT (镧改性锆钛酸铅) 中的二次电光效应实现的单门 PLZT 光开关,并对其性能进行了测试。在 0.85μm 波长上,该光开关的插入损耗为 7dB,消光比为 37.8dB,开关响应速度为 8μs,半波电压为 650V。

A single gate PLZT optical switch using the quadratic electrooptic effect in PLZT ceramics has been designed and tested. At 0.85μm wavelength, the optical switch has the insertion loss of 7dB, extinction ratio of 37.8dB, switching response time of 8μs, and halfwave voltage of 650 volts.

本文发表在 92nd Annual Meeting of American Ceramic Society, Dallas, Texas, USA, 1990

## 超高细度光纤环形谐振腔

### Fiber Ring Resonator with Ultrahigh Finesse

彭江得 岳超瑜 陈抗美 廖延彪 周炳琨

(清华大学)

利用一段普通单模光纤和定向耦合器研制成超高细度的光纤环形谐振腔,从理论上推导并修正了环形腔细度与光纤参量及定向耦合器参量的关系。对于一个 60cm 长的光纤环形腔,采用光纤偏振控制器调整光的偏振态,实验测得光纤环形腔的最高细度达 1260,远高于迄今国外报导的最好指标 (500),并有可能进一步改善。这种器件可望在光纤激光器,光纤频谱分析器和环形腔光纤陀螺中获得主要应用。

A ultrahigh finesse passive fiber ring resonator was formed by a piece of single-mode fiber using a low loss directional coupler to link the fiber into a closed ring. Theoretical derivation of the ring resonator finesse in terms of fiber and directional coupler parameters is given. By using a fiber polarization controller to adjust the polarization of the single-frequency light wave ( $0.6328\mu\text{m}$ ), The finesse of the resonator was measured as high as 1260 on a fiber ring resonator of 60cm length, which is much more than the highest finesse (500) reported so far. Further improvement of resonator finesse is feasible. This device can be used in research on fiber ring lasers, high-resolution optical spectrum analyser and passive or active resonator fiber gyro.

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## 精细度 1260 的光纤环形谐振腔

### Fiber Ring Resonator with Finesse of 1260

岳超瑜 彭江得 廖延彪 周炳琨

(清华大学)

用一段普通单模光纤和一个磨抛型光纤耦合器研制成超高精细度光纤环形谐振腔。环形腔的精细度决定于耦合器的耦合系数和光纤腔的损耗。对于磨抛型光纤耦合器,当光纤包层磨抛到距纤芯数微米,耦合系数便可高达 99%。实验表明,控制残留包层厚度在  $0.2 \sim 0.5\mu\text{m}$  以内,可使耦合器插入损耗最小。当单模光纤 ( $0.6328\mu\text{m}$ ) 衰减损耗为  $8\text{dB/km}$ , 光纤环长为 0.6m 时,计算得到耦合器的插入损耗为 0.14% ( $-0.006\text{dB}$ )。采用 He-Ne 激光作单频光源,实验测得光纤环形腔的精细度高达 1260 (相应的耦合系数

$k=99.7\%$ ), 远高于迄今报导的最好指标 (500)。这种器件可用作高分辨率光频谱分析仪, 并可望在光纤激光器和光纤陀螺中获得应用。

A fibre ring resonator with ultra-high finesse has been constructed by a strand of single-mode fibre and a mechanically lapped coupler. The finesse of the ring resonator is heavily dependent on the coupling constant of the coupler and the internal loss of the fibre loop. It is not difficult to get a coupling constant as high as 99% for a polished coupler when the fibre cladding is polished to within a few microns of the fibre cores. Experimental results show that by leaving  $0.2\text{--}0.5\mu\text{m}$  fibre cladding between the polished fibre surface and the core, we get the lowest insertion loss in the coupler. The insertion loss of the coupler is calculated as  $0.14\%$  ( $-0.006\text{dB}$ ) when the fiber attenuation is  $8\text{dB/km}$  and the ring length is  $0.6\text{m}$ . Using the He-Ne laser as a single-frequency source, the finesse of the ring resonator was measured about 1260 and the coupling constant of 99.75% was calculated. This device can be used in research on fibre ring lasers, passive resonator gyro and high-resolution optical spectrum analyser.

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### 分辨率 $< 10\text{kHz}$ 的扫描光纤环形干涉仪谱宽测量技术

#### Mearsurement of the Spectral Width Using a Fiber Ring Interferometer with the Resolution of $< 10\text{kHz}$

岳超渝 彭江得 周炳琨

(清华大学)

本文提出一种窄线宽激光器线宽测试的新方法。利用高细度光纤环形腔的被测细度随光源谱宽而变的特性, 可用作扫描干涉仪来对光谱线宽进行快速、简便、高分辨率的测量。由于光纤环形腔细度高, 腔长可以做得很长, 自由谱区很窄, 因此在用作谱宽测量时有极高的分辨率。采用普通单模光纤 ( $1.5\mu\text{m}$ ) 研制成  $220\text{m}$  长的环形谐振干涉仪, 分辨率可达  $3.6\text{kHz}$ , 远优于迄今报导的最高谱分辨率 ( $10\text{kHz}$ )。如增加光纤长度, 分辨率还可以进一步提高。

A novel method for mearsuring the linewidth of the narrow linewidth laser is proposed in this paper. As the mearsured finesse of the ring resonator is changed with the source linewidth, we can use it as a scanning interferometer for mearsuring linewidth. Because the finesse of the fiber ring resonator can be very high, the fiber ring can be very long and the free spectrum range (FSR) can be very narrow, hence, a fiber ring resonator interferometer with a high finesse resonator would have very high resolution. The resolution of a fiber ring

resonator of 220m length using the single-mode fiber ( $1.5\mu\text{m}$ ) was as high as 3.6kHz which is much more than the highest resolution (10kHz) reported so far. Further improvement of the revolution is feasible by increase the length of the fiber ring.

本文发表在《1989 光电子器件与集成技术年会》论文集, 第 305~308 页

### 稀土掺杂全光纤激光器与放大器

#### Rare-Earth-Doped All-Fiber Lasers and Amplifiers

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(清华大学)

近年来, 利用稀土元素掺杂光纤研制的光放大器和激光器格外引人注目。采用半导体激光泵浦的高增益、低噪声宽带光纤放大器和低阈值、高效率可调谐光纤激光器已获得成功。但迄今报导的各种器件均采用分离元件(包括如反射镜、分光镜和光栅等)的组合结构, 使这类器件的性能和实用性受到限制。因此, 实现全光纤器件对推进掺杂光纤器件的进一步发展具有重要意义。本文报导我们课题组在这方面的工作进展: 环形谐振腔结构的可调谐掺  $\text{Nd}^{3+}$  和  $\text{Er}^{3+}$  全光纤激光器研制成功, 泵浦—信号光分离耦合注入与输出的全掺  $\text{Er}^{3+}$  光纤光放大器的实验论证, 及全光纤器件的设计和实验结果。

Recently rare-earth-doped fiber lasers and amplifiers have drawn attention as promising contenders for future optical transmission systems. Tunable fiber lasers with low threshold, high efficiency and optical fiber amplifiers with high gain, low noise and large bandwidth have been demonstrated with semiconductor source pumping. However, these devices reported so far are to use separated elements including mirrors, beam splitter or grating, so that some performances of these systems are degraded. Thus, the development of all-fiber devices is of practical importance. In this paper, we describe recent advances in the field in our group. Tunable all-fiber lasers using a  $\text{Nd}^{3+}$ -doped or  $\text{Er}^{3+}/\text{Yb}^{3+}$ -doped fiber ring resonator have been achieved, which have facilitated low loss coupling to transmission fibers.  $\text{Er}^{3+}/\text{Yb}^{3+}$ -doped all-fiber amplifier using dichroic coupler to separate the input and output of the pumping beam from the signal beam has been demonstrated. The design and experiment results of these devices are described.

本文发表在《1989 光电子器件与集成技术年会论文集》, 第 232~236 页

### 可调谐掺 $\text{Nd}^{3+}$ 光纤环形激光器

#### Tunable $\text{Nd}^{3+}$ -Doped Fiber Ring Laser

岳超瑜 彭江得 周炳琨

(清华大学)

用国产  $\text{Nd}^{3+}$  掺杂单模光纤研制成一种新型可调谐全光纤环形腔激光器。掺  $\text{Nd}^{3+}$  光纤通过光纤耦合器连成闭合环形腔，当光纤中的  $\text{Nd}^{3+}$  离子受泵浦光激发时，在光纤环形腔内即形成激光振荡，调整耦合器的耦合系数还可对激光器进行工作波长的调谐。此外，在这种全光纤环形激光器中不存在其他如反射镜及光栅之类的有损元件，因而激光腔的损耗极低。实验中采用  $\text{Ar}^{3+}$  离子激光 (514.5nm) 泵浦，对于腔长 3m 的掺  $\text{Nd}^{3+}$  光纤环形激光器，其阈值泵浦吸收光功率为 1.45mW，单端输出斜率效率为 9.2%，中心波长为 1.088 $\mu\text{m}$ ，波长调谐范围宽达 60nm。

A novel tunable all-fiber laser using a  $\text{Nd}^{3+}$ -doped single-mode fiber ring resonator is reported. In this fiber ring laser the fiber coupler was used not only as a device for coupling the fiber to become a ring cavity but also as a wavelength tuning device. In addition, there are not any reflective elements in the all-fiber ring laser so that the excess loss was very low, End-pumped by an argon laser at 514.5nm wavelength, a lasing wavelength tuning range of 60nm was obtained. The threshold pumping power absorbed by the fiber was 1.45mW and the single end output slope efficiency of 9.2% was obtained.

本文发表在 Electron.lett., 1989, Vol.25, pp.101-102, 及“1989 国际激光与光电子学会议”(CLEO'89, Baltimore, Maryland, 24-28, April, 1989)

### 可调谐掺 $\text{Er}^{3+} / \text{Yb}^{3+}$ 光纤环形激光器

### Tunable $\text{Er}^{3+} / \text{Yb}^{3+}$ -Doped Fiber Ring Laser

彭江得 岳超瑜 周炳琨

(清华大学)

掺  $\text{Er}^{3+}$  光纤激光器因其工作波长 (1550nm) 与光纤通信第三窗口 (1530nm) 相吻合而显得尤为重要。本文报导一种新型环形腔结构的可调谐掺  $\text{Er}^{3+} / \text{Yb}^{3+}$  全光纤激光器。这种激光器由一段掺  $\text{Er}^{3+} / \text{Yb}^{3+}$  光纤通过光纤耦合器相连成环形谐振腔构成。由于  $\text{Er}^{3+}$  离子的激光跃迁属三能级系统，故必须选择合适的光纤长度。在实验中分别设计 38m 和 1m 长的光纤腔，采用  $\text{Ar}^{3+}$  离子激光 (514.5nm) 泵浦，对于 8m 长器件，阈值吸收功率 14.2mW，斜率效率 10.2%；对于 1m 长器件，阈值功率降为 1.9mW，斜率效率为 6.1%，调节耦合器，激光波长可从 1554nm 到 1577nm 连续调谐。

$\text{Er}^{3+}$ -doped fiber lasers radiating at about 1550nm are especially important for application in the third telecommunications window around 1530nm. A novel tunable all-fiber

laser using a  $\text{Er}^{3+}/\text{Yb}^{3+}$  co-doped single mode fiber ring resonator. As the particular  $\text{Er}^{3+}$ -laser transition excited was three-level, it was necessary to select a suitable length of fiber. In our experiment, the  $\text{Er}^{3+}/\text{Yb}^{3+}$  co-doped fiber ring cavities of 8m and 1m were constructed respectively. An argon laser beam (514.5nm) is used as the end pumping source and the laser oscillations occur in both clockwise and anticlockwise direction. For the laser of 8m length, a threshold of 14.2mW was obtained with a slope efficiency of 10.2%, while for the laser of 1m length, a threshold of 1.9mW and a slope efficiency of 6.1% were shown. By adjusting the directional coupler, the lasing wavelength can be tuned continuously from 1554nm to 1577nm.

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### 掺 $\text{Er}^{3+}/\text{Yb}^{3+}$ 全光纤环形激光器的波长调谐

#### Wavelength Tuning of the $\text{Er}^{3+}/\text{Yb}^{3+}$ -Doped Fiber Ring Laser

彭江得 岳超瑜 周炳琨

(清华大学)

工作波长为 1550nm 的可调谐掺  $\text{Er}^{3+}$  光纤激光器在光纤通信应用中有重要意义。既然可调谐全光纤环形激光器的工作基于耦合光纤环形腔中的光谐振及可调光纤耦合器耦合系数与波长的依赖关系, 因而优质磨抛型光纤耦合器的研制, 特别是耦合器的波长选择性的设计, 是实现光纤激光器窄线宽工作并使波长连续调谐的关键。本文详细介绍新型可调谐掺  $\text{Er}^{3+}$  全光纤环形激光器的最佳设计考虑及其实验结果。对于一个  $\text{Ar}^{3+}$  离子激光 (514.5nm) 泵浦的 1m 长掺  $\text{Er}^{3+}$  光纤激光器, 在中心波长 1540nm 附近的连续调谐范围大于 70nm, 最窄线宽小于 0.1nm。

The  $\text{Er}^{3+}$ -doped-fiber laser operating at 1.5 $\mu\text{m}$  is interest for various applications, in particular, the telecommunication purpose. Since the operation of the tunable all-fiber ring laser is relied on the optical resonance in the doped fiber coupled ring cavity and the dependence of the coupling coefficient of the tunable polished fiber coupler on the wavelength, the fabrication of delicate coupler is the key for this all-fiber device and, in particular, the wavelength selectivity of the coupler should be considered carefully in the design to achieve narrow linewidth and a good continuity of wavelength tuning. In this letter, the optimum design and experimental results of a novel  $\text{Er}^{3+}/\text{Yb}^{3+}$ -doped all-fiber ring laser tuned by a fiber coupler are described. For the fiber ring laser of 1m length pumped by an argon laser at 514.5nm, tuning range of more than 70nm and linewidth of less than 0.1nm have been obtained.



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调谐范围  $> 70\text{nm}$  的  $\text{Er}^{3+} / \text{Yb}^{3+}$  掺杂全光纤环形激光器  
A Tunable  $\text{Er}^{3+} / \text{Yb}^{3+}$ -Doped All-Fiber Ring Laser  
with Wavelength Tuning Range of  $> 70\text{nm}$

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一种新型环形腔结构的可调谐  $\text{Er}^{3+} / \text{Yb}^{3+}$  掺杂全光纤激光器研制成功。利用耦合器耦合系数的波长依赖关系, 由单个光纤耦合即可同时完成泵浦光的直通注入、激射光的振荡和工作波长的调谐等三个功能。这种光纤激光器具有阈值低、效率高、波长调谐范围宽的优良特性, 并可与光纤系统直连, 易于实现全光纤网络。本文报导全光纤环形激光器的设计原理及实验结果。用国产  $\text{Er}^{3+} / \text{Yb}^{3+}$  掺杂光纤分别设计了  $8\text{m}$  和  $1\text{m}$  长的激光器, 采用  $\text{Ar}^+$  离子激光 ( $514.5\text{nm}$ ) 泵浦, 对于  $8\text{m}$  器件, 阈值吸收功率  $14.2\text{mW}$ , 斜率效率  $10.2\%$ ; 对于  $1\text{m}$  器件, 阈值功率为  $1.9\text{mW}$ , 斜率效率为  $6.1\%$ , 波长调谐范围宽达  $70\text{nm}$ 。

A novel tunable  $\text{Er}^{3+} / \text{Yb}^{3+}$ -doped fiber laser with the ring resonant structure has been demonstrated. By using the dependence of the coupling coefficient of the variable fiber coupler on the wavelength, the straight forward transmission of the pumping light, the oscillation of the lasing light and the tuning of the operating wavelength are simultaneously achieved. This fiber ring laser has a low loss cavity so that it has a low threshold and high slope efficiency, and can connect with fiber systems directly. The design and experimental results are reported in this paper. In our experiment, the  $\text{Er}^{3+} / \text{Yb}^{3+}$  co-doped fiber ring cavities of  $8\text{m}$  and  $1\text{m}$  were constructed respectively. An argon laser beam ( $514.5\text{nm}$ ) is used as the end pumping source. For the laser of  $8\text{m}$  length, a threshold of  $14.2\text{mW}$  was obtained with a slope efficiency of  $10.2\%$ , while for the laser of  $1\text{m}$  length, a threshold of  $1.9\text{mW}$  and a slope efficiency of  $6.1\%$  were obtained. By adjusting the coupler, a tuning range of  $> 70\text{nm}$  was shown.

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光纤环形激光器  
Fiber Ring Lasers

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光纤激光器通常采用在光纤两端贴膜或直接镀膜构成的法布里-珀罗谐振腔结构。为调谐波长, 必须采用腔内光纤作为波长调谐元件, 由于光栅腔的损耗很大, 这种激光器的阈值很高, 斜率效率很低, 而且难以直接与光纤系统连接。在我们设计的新型全光纤环形激光器中, 仅单个磨抛型光纤耦合器将掺杂光纤连成环形谐振腔, 利用耦合器的波长选择性, 即可同时实现泵浦激光光的分离耦合、激光光振荡和激光波长的调谐, 采用复合环形腔结构, 还能实现激光器的单纵模运转。这种全光纤激光器阈值极低, 斜率效率很高, 并可直接与光纤系统相连。本文报导掺  $\text{Nd}^{3+}$  和掺  $\text{Er}^{3+} / \text{Yb}^{3+}$  全光纤环形激光器及新近研制的单纵模光纤环形激光器, 最窄线宽小于 40MHz。

Conventional fiber lasers have a structure of Fabry-Perot resonator formed by two mirrors on both end of the fiber or by coating the dielectric film mirrors directly on the end surfaces of the fiber. A tunable fiber laser usually uses a grating as the wavelength selective element in the laser cavity. Because of the high loss of the grating cavity, this kind of fiber laser has high threshold and low slope efficiency, moreover, the laser output cannot be directly connected with fiber systems. In our specially designed all-fiber ring laser, a tunable directional coupler was not only as a device for linking the rare earth doped fiber to form a ring resonator but also as a wavelength tuning element. This fiber ring laser has a low loss cavity so that it has a low threshold and high slope efficiency, and can connect with fiber systems directly. In this paper,  $\text{Nd}^{3+}$  and  $\text{Er}^{3+}$  doped fiber ring lasers and a novel single longitudinal mode fiber ring laser with the laser line-width of  $< 40\text{MHz}$  are investigated and discussed.

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### 制作 InP 光栅的全息光刻法

#### The Fabrication of InP Holographic Grating

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周期性结构在集成光学中有广泛应用, 高速通信系统的 DFB 单频激光器, 就是利用光栅作为选模机构的。

两相干光对涂有光刻胶的基片曝光。选择适当的曝光及显影参数, 可在 InP 衬底上形成光栅掩膜。坚膜后, 用  $\text{Br}_2\text{-H}_2\text{O}$  或  $\text{HBr-HNO}_3\text{-H}_2\text{O}$  腐蚀即可。

选择曝光及显影参数是非常重要的, 良好的曝光参数有利于成品率的提高。

Period structures can be widely used in Opto-electronic devices. DFB lasers, used in high bit rates transmission systems, make use of Grating as a model selector.

Exposed in two coherent plant waves and then developed, the InP substrat, sputtered with Photoresist, can ba masked in the forms of the Grating. Etched it by a  $\text{Br}_2\text{-H}_2\text{O}$  or an  $\text{HBr-HNO}_3\text{-H}_2\text{O}$  solotions after baked .

The selection of exposing and developing datas is important, because of the relevance to the yield rate.

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### DFB 激光器光谱特性及其分析

#### Spectra Character and Its Analysis of DFB Lasers

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用三步 LPE 生长, 二级光栅刻蚀技术制造  $1.55\mu\text{m}$  波段 GaInAsP DFB-DC-PBH 激光器, 在高速直接调制下 ( $1.4\text{Gbit/s}$  NRz 码或  $1\text{GHz}$  正弦信号, 偏置电流  $1.1$  至  $1.8I_{\text{th}}$ ) 下单纵模工作稳定, 边模抑制比大于  $19\text{dB}$ , 光谱线宽小于  $100\text{MHz}$ 。

A  $1.55\mu\text{m}$ -wavelength GaInAsP DFB-DC-PBH LDs was fabricated by three-step LPE growth process. The second order corrugation grating was formed. Single longitudinal mode operation maintained under high speed direct modulation ( $1.4\text{Gbit/s}$  NRZ or  $1.0\text{GHz}$  sinewave, bias current from  $1.1$  to  $1.8I_{\text{th}}$ ). Side-mode -suppression-ratio was larger than  $19\text{dB}$ . Spectral linewidth was narrower than  $100\text{MHz}$ .

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### $1.55\mu\text{m}$ GaInAsP / InP DFB-DC-PBH 激光器

#### $1.55\mu\text{m}$ GaInAsP / InP DFB-DC-PBH Laser Diode

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在 n-InP 衬底或 GaInAsP 波导层上, 使用氩离子激光器全息曝光方法刻制二级光栅, 进行低温液相外延生长。再利用已有的 DC-PBH 激光器的制作工艺技术, 构成了分布反馈双沟道平面掩埋异质结激光器 (DFB-DC-PBH)。15℃ 连续工作最低阈值电流为

63mA, 典型值 70~120mA, 线性输出功率大于 4mW, 外微分量子效率为 5~8.3%, 主模波长  $\lambda$ 。温度漂移系数  $\Delta\lambda/\Delta T$  为 0.8~1.0/°C, 静态单纵模较好, 在 400Mbit/s, 700Mbit/s 和 1.4Gbit/s, 20mA 电流随机码调制下, 单纵模工作稳定。相同条件下, DC-PBH LD 单纵模明显变为多模或跳模。

On a n-InP substrate or a GaInAsP waveguide layer, the authors have engraved the second-order grating by holographic lithography and fabricated DFB-DC-PBH LDs with technology of DC-PBH LD. The lowest CW threshold current was 63 mA at temperature of 15°C, the typical values were in the range of 70~120 mA. The temperature dependence of lasing wavelength was about 0.8~0.1nm/deg. 20 percent of the LDs exhibited stable static single-mode operation. Under 700 Mbit/s and 1.4Gbit/s pseudorandom modulation rates, the single longitudinal mode output remains in good stability.

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### 1.55 $\mu$ m 分布反馈激光器

#### 1.55 $\mu$ m Distributed Feedback Lasers

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用二级光栅制作的 DFB-DC-PBH 激光器, 最低阈值电流 (15°C) 为 40mA, 典型值 50~90mA, 线性输出功率大于 4mW, 主模波长随温度漂移系数  $\Delta\lambda/\Delta T$  为 0.09nm/°C, 1.4Gbit/s 伪随机码调制下 (调制电流 20mA), 单纵模工作保持稳定。

The DFB-DC-PBH LDs have been developed with the second-order grating. The characteristics of the device are that the lowest  $I_{th}(15^\circ\text{C})$  was 40mA, typical values are 50~90 mA, the linear output power was more than 4 mW, the main mode wavelength-temperature efficiency  $\Delta\lambda/\Delta T$  was 0.09nm/°C. Under 1.4Gbit/s pseudorandom modulation rates of 20 mA amplitude, the single longitudinal mode operation remains stability.

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### 国产 GaAlAs 激光器的超高频调制特性

#### Ultra-High Frequency Modulation

#### Characteristics of Domestic GaAlAs Lasers

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本文对国产 GaAlAs 半导体激光器的超高频调制特性进行了实验研究和理论分析。发现国产 GaAlAs 激光器调制带宽和国外先进水平相比有较大差距。通过理论分析,弄清了限制国产半导体激光器调制带宽的主要因素,找到了提高国产半导体激光器调制带宽的有效途径。

Ultra-high frequency modulation characteristics of domestic GaAlAs semiconductor lasers are studied experimentally and analysed theoretically. It is found that the modulation bandwidth of these lasers is under 1000MHz. Analytical results show that the main factors confining the modulation bandwidth of these lasers are the parameters  $L_s$  and  $C_j$ , the bonding wire inductance and the junction capacitance. A proposal for improving modulation characteristics of domestic semiconductor lasers is given.

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### 半导体激光器脉冲调制理论分析

#### Theoretical Analysis of Pulse Modulation of Semiconductor Lasers

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本文用龙格-库塔法求解高斯脉冲调制下半导体激光器速率方程,对结果进行了分析。推出了较高偏置直流和高斯脉冲调制下计算激光脉冲延迟时间、脉冲宽度和最大调制码率的公式。给出了调制畸变的实验结果。

Rate equations of Gaussian shape pulse modulated semiconductor lasers are solved by Runge-Kutta method, and the results are analysed. The formulae for calculating the delay time, pulse width of laser pulse and maximum bit-rate of Gaussian shape pulse modulation are derived. The experimental results of modulation pattern effects are given.

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### 高重复率半导体超短脉冲激光的产生和测量

#### Generation and Measurements of Ultrashort Laser Pulses at High Repeat Rate

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王首山 蔡德芳 过己吉  
(西安电子科技大学)

本文介绍直接调制 DH-AlGaAs 半导体激光器产生高重复率超短脉冲激光和有关测量的实验结果。激光脉冲重复频率可在 150MHz~1GHz 范围内变化, 脉冲宽度为 30~40ps。用碘酸锂晶体进行光倍频对激光脉冲进行了二阶自相关测量, 确定了脉冲宽度。

The experimental results of generation of ultrashort laser pulses at high repeat rate and related measurements are presented. The repeat rate of laser pulses can vary in the range from 150MHz to 1GHz. The pulse width is 30~40ps. Laser pulse width has been measured by the LiIO<sub>3</sub>SHG autocorrelation method.

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### DH-GaAlAs 激光器的非对称脉冲振荡研究

#### Study of Asymmetrical Pulse Oscillation in AlGaAs DH Lasers

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本文报道了 DH-GaAlAs 半导体激光器的非对称激光脉冲振荡的实验观察结果。用求解激光器的速率方程得出的数值解, 可较好地解释所观察到的非对称激光脉冲振荡现象。通过计算给出了半导体激光器的非对称脉冲振荡工作区, 即产生非对称激光脉冲时, 偏置直流、射频电流和调制频率的范围。

The experimental observations on asymmetrical pulse oscillation in DH-AlGaAs semiconductor lasers are presented. There phenomenon of asymmetrical pulse oscillation, which were discovered for the first time in semiconductor lasers, can be explained by use of the numerical solution of the laser rate equations. The region in which the DH-GaAlAs lasers operate in asymmetrical pulse oscillation mode can be determined by computing, that is, the range of bias current, RF current and modulation frequency for generating asymmetrical laser pulses can be determined.

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### 高重复率半导体激光脉冲晃动的研究

## Study of the Jitter of Semiconductor Laser Pulses at High Repeat Rate

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半导体激光器的本征噪声是一种散弹噪声, 其影响之一是导致激光脉冲的晃动。作者通过求解含有散弹噪声项的速率方程, 得出了小信号调制下脉冲晃动和噪声之间的关系。并对大信号调制下的速率方程进行了数值求解, 得出了脉冲晃动时间的均方根值, 它与偏置电流、调制深度和调制频率有关。最后, 对脉冲晃动进行了实际测量, 表明实验结果与理论分析相符。

The intrinsic noise of semiconductor lasers is a kind of shot noise and one of its effects results in the jitter of laser pulses. By solving the rate equations with shot noise terms, the relationship of jitter with noise is obtained in the case of small signal modulation. Utilizing the numerical solution of rate equations under large signal modulation, the RMS jitter time, which depends on bias current, modulation depth and frequency, is determined. Finally, the pulse jitter is measured experimentally, and shows that the experimental results are coincident with theoretical analyses.

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## 超高速半导体激光二极管组件

### Ultra-high Speed Semiconductor Laser Diode Modules

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报导了一种超高速 DH-GaAlAs 半导体激光二极管组件, 其调制带宽超过 2GHz, 一些组件达到 3.2GHz。对 GaAlAs 半导体激光芯片的超高频电路参数进行了精确的测量, 然后用微波集成电路的理论和工艺设计并制作了组件。这不但使引线电感大大降低, 而且还克服了寄生分布参数的不良影响, 使调制带宽大幅度提高。本文详细介绍了超高速组件的设计、工艺考虑和实验结果。同时, 还讨论了进一步提高组件的调制速度的途径。

A Kind of ultra-high speed DH-GaAlAs semiconductor laser diode modules is reported. These modules have modulation frequency band over 2GHz and some of them up to 3.2GHz. After accurately measuring the ultra-high frequency circuit parameters of the laser chips, we designed and made the modules by use of the theory and technology of microwave integrated circuit. This does not only reduce the inductance largely, but over-

come the bad influence of parasitical distributed parameters and increase the width of modulation band. In this paper, the design, technology consideration and experimental results of these modules are presented in detail and the method to promote the modulation speed of modules is discussed as well.

本文发表在“高技术信息领域光电子主题 89'光电子器件与集成技术年会”

### 采用激光二极管作光源的光电子取样系统

#### High Speed Optoelectronic Sampling System with LD Sources

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近年来用半导体激光器产生超短光脉冲取得了巨大进展。在光电子取样系统中,染料激光器被激光二极管所取代,而灵敏度和分辨率对工业应用仍是合适的。在我们的样机中,采用了两只微波调制的激光二极管和一只 SOS 或 InP 光电导。激光脉冲宽度和光电导器件的响应时间保证系统的瞬时响应优于 40ps。激光器的输出功率使系统足够灵敏。系统具有很小的尺寸,和普通取样示波器一样大小,加之其成本低、高可靠和无抖动触发,使该取样系统在工业中非常有用。

In recent years, a great progress has been made in generating ultrashort optical pulses in semiconductor laser diode (LD). In this Optoelectronic Sampling System, the dye laser is replaced with pulses LDs and the sensitivity and the resolution are reasonable for industry application. In our primary embodiment, two microwave modulated DH-GaAlAs laser diodes and a sosor Inp photoconductor are utilized. Thewidth of the laser pulse and the response time of photoconductor devices guarantee the temporal resolution of the system better than 40ps. The output of LDs makes the system sensitive enough. The system has small sizes like a common oscilloscope. Including the low cost, high reliability and jitter free triggering, the sampling system is very useful in industry.

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### 超高速长波长 PIN 探测器

#### High Speed InGaAs PIN-PD

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用液相外延研制 InGaAs 长波长 PIN 探测器。器件采用背面照射平面结构以减小结电容、寄生电容,提高量子效率。实验表明,高温性、可靠稳定性优于台面结构。其中吸收层 InGaAs 为  $3\mu\text{m}$ ,浓度为  $(3\sim 6) \times 10^{15} / \text{cm}^3$ 。

器件的光敏面有直径  $70\mu\text{m}$  和  $40\mu\text{m}$  两种,反向电流均小于 1 个 nA,击穿电压 50V,管芯结电容 0.4pF 和 0.2pF,灵敏度  $0.7\mu\text{A} / \mu\text{W}$ ,直径  $70\mu\text{m}$  的器件,测量的上升时间 50ps, FWHW90ps。用网络分析仪测量了 S 参数,计算机等效电路模拟与测试结果相符。

A high speed InGaAs PIN photodetector has been fabricated using LPE. A planar back light incidence struction is designed to reduce junction capacitance, parasite capacitance and enhance quantum efficiency. Such a struction demonstrates more reliability, suprior temperature characteristics to that of the mesa-struction. Thickness of the absorption InGaAs layer is  $3\mu\text{m}$ , the background electron intensity is in the range of  $(3\sim 6) \times 10^{15} / \text{cm}^3$ .

The results show that, for two different absorption area,  $\phi 70\mu\text{m}$  and  $\phi 40\mu\text{m}$ , the breakdown voltage is 50V, sensitivity  $0.7\mu\text{A} / \mu\text{W}$ , junction capacitance 0.4pF and 0.2pF respectively, and the reverse current no more than 1 nA. The measured rising time is 50ps, FWHW 90ps. S parameters of the device is measured with a net-analyser. And the calculated results using computer analysis is consistent with the measured results.

本文发表在《光电子器件与集成技术年会论文集》,1989 年

### 1.55 $\mu\text{m}$ 分布反馈激光器

#### 1.55 $\mu\text{m}$ Distributed Feedback Lasers

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用二级光栅制作的 DFB-DC-PBH 激光器,最低阈值电流 ( $15^\circ\text{C}$ ) 为 40mA,典型值 50~90mA,线性输出功率大于 4mW,主模波长随温度漂移系数  $\Delta\lambda / \Delta T$  为  $0.09\text{nm} / ^\circ\text{C}$ , 1.4Gbit / s 伪随机码调制下 (调制电流 20mA),单纵模工作保持稳定。

The DFB-DC-PBH LDs have beed developed with the second-order grating. The characteritics of the device are that the lowest  $I_{th}(15^\circ\text{C})$  was 40mA, typical values are 50~90mA, the linear output power was more than 4mW, the main mode wavelength-temperature efficiency  $\Delta\lambda / \Delta T$  was  $0.09\text{nm} / ^\circ\text{C}$ . Under 1.4Gbit / s pseudorandom modulation rates of 20 mA amplitude, the single longitudinal mode operation remains stability.

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### DFB 激光器光谱特性及其分析

#### Spectra Character and Its Analysis of DFB Lasers

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(武汉电信器件公司)

用三步 LPE 生长, 二级光栅刻蚀技术制造  $1.55\mu\text{m}$  波段 GaInAsP DFB-DC-PBH 激光器, 在高速直接调制下 ( $1.4\text{Gbit/s}$  NRZ 码或  $1\text{GHz}$  正弦信号, 偏置电流  $1.1$  至  $1.8I_{\text{th}}$ ) 下单纵模工作稳定, 边模抑制比大于  $19\text{dB}$ , 光谱线宽小于  $100\text{MHz}$ 。

A  $1.55\mu\text{m}$ -wavelength GaInAsP DFB-DC-PBH LDs was fabricated by three-step LPE growth process. The second order corrugation grating was formed. Single longitudinal mode operation maintained under high speed direct modulation ( $1.4\text{Gbit/s}$  NRZ or  $1.0\text{GHz}$  sinewave, bias current from  $1.1$  to  $1.8I_{\text{th}}$ ). Side-mode-suppression-ratio was larger than  $19\text{dB}$ . Spectral linewidth was narrower than  $100\text{MHz}$ .

本文发表在“Second Sino-Hungarian Joint Seminar on Optical Communication”  
会议文集上, 20-24 October, 1989

### 制作 InP 光栅的全息光刻法

#### The Fabrication of InP Holographic Grating

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(武汉邮电科学研究院)

周期性结构, 在集成光学中有广泛应用, 可用于高速通信系统的 DFB 单频激光器, 就是利用光栅作为选模机构的。

两相干光对涂有光刻胶的基片曝光, 选择适当的曝光及显影参数, 可在 InP 衬底上形成光栅掩膜。坚膜后, 用  $\text{Br}_2\text{-H}_2\text{O}$  或  $\text{HBr-HNO}_3\text{-H}_2\text{O}$  腐蚀即可。

选择曝光及显影参数是非常重要的, 良好的曝光参数有利于成品率的提高。

Period structures can be widely used in Opto-electronic devices. DFB Lasers, used in high bit rates transmission systems, make use of grating as a model selector.

Exposed in two coherent plant wares and then developed, the InP substrate, sputtered with photoresist, can be masked in the forms of the grating. Etched it by a  $\text{Br}_2\text{-H}_2\text{O}$ , or an  $\text{HBr-HNO}_3\text{-H}_2\text{O}$  solutions after baked.

The selection of exposing and developing dates is important, because of the relevance to the yield rate.

本文发表在《全国第四届光通信会议文集》

### 用 LBO 测量飞秒超短光脉冲

#### Femtosecond pulses measurement with LBO

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新的非线性光学晶体 LBO 用于飞秒 (fs) 超短脉冲自相关测量, 测出了 CPM 激光器输出最短脉宽 (FWHM) 为 52fs, 和用同样厚度 KDP 晶体测量结果相同。并通过调节 CPM 腔内棱镜组的色散补偿使输出脉宽发生变化, 用 LBO 和 KDP 观察了变化情况。我们通过测量锁模脉冲的谱宽及计算基波和谐波之间的群速度失配量分析了测量精度。实验还测出了 LBO 接收角  $= 7.95^\circ$  (全角), 比 KDP 要大得多。通过实验我们论证了新晶体 LBO 具有高的光学质量、好的化学和物理稳定性、大的有效 SHG 系数和大的接收角、小的离散角等光学特性。

In this letter, we demonstrated the use of the nonlinear optical crystal LBO for autocorrelation measurements of femtosecond ultrashort optical pulse, and measured the shortest pulse duration about 52 fs generated from the CPM dye laser. The result is greatly in concordance with the one obtained using the same thickness KDP. Adjusting the CPM intracavity dispersion compensation prisms, we observed the change of the pulse duration using LBO and KDP respectively. And then, we analysed the measurement accuracy by measuring the bandwidth of the modelocked pulse and calculating the mismatch of the group velocity between the base and harmonic. We also obtained the angular acceptance of LBO about  $7.95^\circ$  (whole angle), which is much greater than that of KDP. By experiment we conclude that this new kind of crystal LBO has high optical quality, good chemical and physical stability, large effective SHG coefficients, big angular acceptance and small walk-off angle.

本文发表在“第肆届全国光电技术与系统学术会议”

### 飞秒激光超高速电光采样

#### Femtosecond Laser Used in Ultrafast Electro-Optic Sampling

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飞秒激光与本征应庆速度为  $10^{-15}$ s 的电光 Pockels 效应相结合形成的超高速电光采样技术使最近几年出现的, 响应速度为几皮秒, 带宽达几百吉赫的快速电子-光电子学材料和器件的测量和表征成为可能。

本文介绍这种电光采样技术的原理和应用, 设计和制做了 Cr-GaAs 光电导超快电脉冲产生器和 LiTaO<sub>3</sub> 高速行波 Pockels 电光调制器, 分别用两束经过可变延迟的碰撞脉冲锁模 (CPM) 激光器产生的脉宽 < 100fs, 重复率约为 80MHz 的超短激光脉冲序列, 作为微带光电导开关的激发光源和 Pockels 盒的探测光束, 产生并测出了前沿上升时间 < 5ps 的超快电瞬变波形。理论和实验均表明, ps 电脉冲传输效应是快速电子学和光电子学中最重要问题之一, 文中分析了超短电脉冲的传输, 并给出了我们制做的微带传输线色散的一些实验测量结果, 对于微带宽度为 300micron, 介质厚度为 300micron 的标准微带器件, 在距电脉冲产生隙 1, 1.25, 1.5 和 2mm 处, 分别测得脉冲前沿上升时间 (从 10%~90%) 为 5, 6, 7 和 9ps。

Ultrafast electro-optic sampling technique developed a few years ago was the combination of fs laser and eletro-optic Pockels effect with fs intrinsic response speed. This technique has made it possible to express and measure the high speed electronic-optoelectronics material and device with picoseconds response speed and hundreds GHz bandwidth.

This report introduced the principal and the application of this kind of technique. We have designed and fabricated a Cr-GaAs optoelectric conducting ultrafast electrical pulse generator and a LiTiO<sub>3</sub> high speed travelling wave Pockels electro-optic modulator. Two laser beams which were beamsplittered from CPM ring dye laser system with duration less than 100 fs and repetition rate around 80MHz were used in our sampling system, one of which was used as the excitation beam, and the other, with a variable delay, as the probe beam. We have generated and probed a transient eletrical pulse with its resetime < 5 ps. It was indicated theoretically and experimentally that ps electrical pulse transmission effect was one of the most important problem in ultrafast electronics and optoelectronics. This report has analyzed the transmission of ultrafast electrical pulse and some experimental results about the transmissionline dispersion with the stripline made by ourselves. For some standard stripline devices with 300 micron wide stripline and 300 micron thick LiTiO<sub>3</sub>, we have probed electrecal pulse rise time (10%~90%) of 5,6,7 and 9ps at the spots of 1,1.25, 1.5 and 2mm away from the gap where the electrical pulses were generated.

本文发表在“第二届全国超快现象学术会议”

## 一种用皮秒激光脉冲实现高分辨率光学探测的方法

### A New Method for ps-Pulse Optical Probe with High Resolution

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本文提出一种用通常锁模技术容易得到的皮秒激光脉冲实现高分辨率光学探测的新方法,它是基于部分锁模皮秒激光脉冲的非线性相关探测。用相关轨迹上的相干尖峰作为“游标”,当把样品插到自相关器两个臂的一路时,通过测量相干尖峰的位移,就能以很高的精度求出样品的光学厚度,对反射或漫射物体,可用它取代相关器固定臂中的端反射镜,测量不同反射间的时间延迟便可实现对样品线度的测量,其空间分辨率可达微米量级,文章还给出了用这种方法测量染料激光器用的染料喷流厚度分布的实例。

This letter introduced a new method for ps optical pulse probe with high resolution which can be easily obtained by conventional modelocking technique. It was based on the nonlinear autocorrelation measurement for the partially mode-locked ps laser pulse. The coherent peak above the correlation track was used as the moving standard scale, by inserting the sample into one of the two legs of correlator and measuring the displacement of the coherent peak, the optical thickness of the sample was obtained with high precision. For reflective or scattering object, it can be put in the correlator to replace the end mirror of the rigid leg. By detecting the delay-time between the two reflections, the dimension of the sample can be measured with a space resolution of micrometer. This letter also gave the measures of the dye jet thickness distribution as an example.

本文发表在“光电子学术年会”, 1989 年

## LiB<sub>3</sub>O<sub>5</sub> 晶体的飞秒脉冲倍频

### Second Harmonic Generation of Femtosecond Pulses in LiB<sub>3</sub>O<sub>5</sub>

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本文报导了非耗尽状态下 LiB<sub>3</sub>O<sub>5</sub>(LBO)晶体对碰撞脉冲锁模环形染料激光器(CPM)产生的 80fs 超短脉冲进行腔外倍频获得紫外辐射的实验结果,对线宽极限飞秒超短脉冲的倍频特性进行了解分析与计算,结果与实验基本一致。

Experimental investigation of LiB<sub>3</sub>O<sub>5</sub>(LBO) for non-depletion state second harmonic generation (SHG) of 80fs optical pulses produced by CPM laser into the ultraviolet is reported. The characteristics of SHG from band-width limited femtosecond pulses are ana-

lysed. The theoretical solutions generally agree with our experimental results.

本文发表在“1990's CLEO”

## 二次谐波法测量低重复率飞秒超短脉冲 SHG Method for Measuring Low-Repetition Rate fs Ultrashort Pulse

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(中国科学院上海光学精密机械研究所)

二次谐波法常用来测量高重复率超短脉冲的脉宽。本文介绍一种用二次谐波法测量低重复率超短脉冲脉宽的方法, 迈克耳逊干涉仪的可变延迟臂由微机控制的步进马达(1micron/步)驱动, 微机发出的控制信号由飞秒激光脉冲同步触发, 用 KDP 晶体 I 类非共线倍频, 无背景紫外(0.305~0.31micron)输出用 PMT 接收后经微机积分平均, 逐点记录后描绘出飞秒低重复率脉冲的相关曲线并获得其脉宽。测量时还分出一束基频光作为参考光以扣除激光系统的抖动噪声。

Second harmonic generation (SHG) is conventionally used to measure the duration of high-repetition-rate ultrashort laser pulse. This letter introduced this SHG method to measure the duration of lowrepetition rate pulse, the variable delay leg of the Michelson interferometer was moved by a stepping motor(1micron/step) which was controlled by a microcomputer. The microcomputer was triggered synchronously by the fs laser pulse, and after that, it sent the controlling signals to the stepping motor. SH wave was generated by nonconlinear frequency-doubling with KDP under I phase-matching. The background free UV SH wave(0.305-0.31micron) was received by a PMT, which then was recorded, integrated and averaged by the computer. By spot-spot recording, we can get the autocorrelation profile and the pulse duration was obtained. For measuring precisely, a reference pulse, beamsplittered from the fundamental pulse, was used to average out the noise of the laser system.

本文发表在“第四届全国光电子技术与系统学术会议”

## 半导体异质结定向耦合器的设计 Design of Semiconductor Hetero-Structure Directional Coupler

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本文根据半导体材料的特点, 分析比较了几种不同结构的条波导在构成定向耦合器时, 对器件性能产生的影响。从而选定异质结加载条波导构成我们的器件。依据平面波传输可等效为传输线传输的原理, 求解出具有多层结构的平面波导的特征方程, 应用等效折射率法和耦合模理论, 结合现有工艺条件, 借助计算机对波导结构参数与器件参数之间的关系进行了数值模拟。经过优选之后, 给出了几个实用 InP-InGaAsP 单模定向耦合器的设计值。

According to the properties of semiconductor, several kinds of strip waveguide structures of a directional coupler are studied. We present a hetero-structure strip-loaded film waveguide which is suitable to coupling. Using the principle of plane wave propagation equivalent to transmission line, we derive the eigenvalue equation of multilayer plane waveguide. On the bases of equivalent refractive index method and coupling mode theory, taking account of the technological conditions, we obtain the relationship of waveguide structure and device parameters by means of numerical simulation. Through optimization, several design results of physical InP-InGaAsP monomode directional couplers are given.

Key words: integrated optics, directional coupler, optical device, optical waveguide.

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## 四、光电子集成器件 Optoelectronic System Integration Device

### PHRCL-BH LD / LPEC-MESFETs OEIC 光发射机结构及工艺特点

#### Structure and Process Advantages of PHRCL-BH LD / LPEC-MESFETs OEIC Transmitter

胡礼中 沈澎乔 张皓月 苏士昌 刘式墉 高鼎三  
(吉林大学)

本文报道 PHRCL-BH LD / LPEC-MESFETs OEIC 光发射机的结构及制作工艺特点。这种新器件将水平和竖直集成结构的优点集于一体, 解决了器件平面化和光电器件间的工艺共容性问题, 为 OEIC 器件的研制开辟了一条新的可行途径。

In this paper, the structure and process advantages of PHRCL-BH LD / LPEC-MESFETs OEIC transmitter were reported. The strong points of the horizontal and the vertical integrated structures have been ingeniously incorporated into this new OEIC structure. Therefore, the problems of the conventional structure planarity and the processing-Compatibility between the optoelectronic and the electronic components were solved. This opened up a new feasible way to OEIC device fabrication.

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### 宽沟道 SI-GaAs 衬底上适于光发射机制作的 BH 激光器

#### A Buried-Heterostructure Laser on Etched-groove SI-GaAs Substrate for the Fabrication of a Transmitter

张皓月 胡礼中 杨东辉 刘式墉  
(吉林大学)

在宽沟道 SI-GaAs 衬底上制成了一种适于单片集成光发射机制作的 AlGaAs / GaAs BH 激光器。室温下, 这种器件的 CW 阈值电流为 70mA。

A AlGaAs / GaAs BH Laser was fabricated on etched-groove SI-GaAs substrate for the fabrication of an integrated optoelectronic transmitter. The CW operation with the threshold of 70mA was achieved at room temperature.



本文发表在 1989 年《第五届全国集成光学学术讨论会论文集》

### 离子交换法平面微透镜列阵及其最佳折射率分布

#### The Ion-exchanged Planar Microlens Array and Its Optimum Index Distribution

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平面微透镜是用平面工艺和离子交换法在玻璃基片上一次获得的微透镜阵列, 每个微透镜元的折射率近似呈球对称分布, 因而可具有透镜性能。文中就这种变折射率微透镜列阵的制作理论——扩散方程作了初步探讨, 提出了掩盘式平面微透镜的概念, 并推导出了它应具备的最佳折射率分布。

Planar microlens array is a device made by planar technique and ion-exchanged method in a glass substrate. The index distribution of the lens lit is approximately spherical symmetry, so the lens lit has lens effects. The paper made a primary discussion on the fabrication theory, diffusion equation of gradient index microlens array, and suggested a discmask planar microlens and derived the optimum index distribution for the lens.

本文发表在“第三届全国纤维光学与集成光学学术交流会”, 《第二届全国光计算技术研讨会论文集》, 1988 年

### 两种离子交换型变折射率微透镜

#### Two Gradient-Index Planar Microlens Arrays

高应俊 章亚丽

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本文首次鲜明地提出两种离子交换类型, 即掩盘式和开孔式平面变折射率微透镜列阵。由它们的制作特点, 根据离子交换理论, 确定了它们相应的离子扩散方程和定解条件, 并首次求出了它们的解析解; 由成像特点进行分析, 推导出了掩盘式微透镜的最佳折射率分布; 由近轴光线追迹, 给出了平面微透镜的成像传输矩阵; 制得发散型掩盘式平面微透镜阵列, 并给出其成像照片及基本测试参数。

The paper clearly presented two ion exchanged, the disk and window mask, planar gradient index microlens array. The diffusion equations and the condition for solving the

solutions were determined from the fabrication features and diffusion theory, the analytic solutions were found; the optimum index distribution for the disk-mask microlens was derived; the image matrix of planar microlens was obtained from the paraxial ray trace. The authors fabricated a disk-mask microlens array, and showed the image picture and parameters.

本文发表在《1989年光电子器件与集成技术年会论文集》，1989年

### 平面微透镜折射率分布的表达 The Index Expression of Planar Microlens

章亚丽 高应俊 薛鸣球

(中国科学院西安光学精密机械研究所)

对平面微透镜的光线追迹、制作指导、测量分析，都离不开折射率的表达式。本文用最小二乘法将测得的数据拟合为一四维矩阵，写出了准球对称分布的折射率解析式，并以物理模型和 Luneburg 透镜模型两个出发点进行了讨论和比较。

The optical path tracing, fabrication guiding, measurement analyzing for planar microlens is closely related with the index expression. The paper fitted the experiment data to a four dimension matrix by the least square method, and wrote out the analytic index equation for a quasi-spherical symmetry distribution, and also made a discussion and comparison by the physical and Luneburg lens model.

本文发表在“第三届全国纤维光学与集成光学学术交流会”，及《第二届全国光计算技术研讨会论文集》，1988年

### 平面微透镜阵列的制作 Fabrication of Planar Microlens Array

章亚丽 高应俊 薛鸣球 刘德森

(中国科学院西安光学精密机械研究所)

随着变折光学的发展和在实际应用中的深入，生产大量的微光电路已势在必行。本文对其中的基础器件平面微透镜阵列的制作作了简要介绍，包括镀膜和光刻工艺，离子交换工艺。并首次在玻璃基片上制得掩盘式平面微透镜列阵，透镜元的焦距  $f = -21\text{mm}$ ，分辨率  $R = 361\text{ps/mm}$ 。文中还给出了该掩盘式微透镜列阵的成像照片。

With the deep development and wide applications of gradient index optics, the mass production of micro-optical circuits is imperative. The paper introduced the fabrication of the basic device—planar microlens array, involved the mask preparation, photoetching, ion-exchanged, and succeeded in fabricating a disk-mask planar microlens array. The lens lit focal length  $f=-21\text{mm}$ , resolution  $R=361\text{ps/mm}$ , the picture taken with the array is also shown.

本文发表在“第三届全国纤维光学与集成光学学术交流会”，《第二届全国光计算技术研讨会论文集》，1988年

### 两种离子交换型变折射率微透镜

#### Two Gradient-Index Planar Microlens Arrays

高应俊 覃亚丽

(中国科学院西安光学精密机械研究所)

本文首次鲜明地提出两种离子交换类型，即掩盘式和开孔式平面变折射率微透镜阵列。由它们的制作特点，根据离子交换理论，确定了它们相应的离子扩散方程和定解条件，并首次求出了它们的解析解；由成像特点进行分析，推导出了掩盘式微透镜的最佳折射率分布；由近轴光线追迹，给出了平面微透镜的成像传输矩阵；制得发散型掩盘式平面微透镜阵列，并给出其成像照片及基本测试参数。

The paper clearly presented two ion exchanged, the disk and window mask, planar gradient index microlens array. The diffusion equations and the condition for solving the solutions were determined from the fabrication features and diffusion theory, the analytic solutions were found; the optimum index distribution for the disk-mask microlens was derived; the image matrix of planar microlens was obtained from the paraxial ray trace. The authors fabricated a disk-mask microlens array, and showed the image picture and parameters.

本文发表在《1989年光电子器件与集成技术年会论文集》，1989年

### 塑料自聚焦复合透镜面列阵研究

#### Preparation of the Plastic

#### Gradient-Index Sphere Lens

刘德森 陈 偶

(中国科学院西安光学精密机械研究所)

本文讨论了塑料梯折球透镜的制作工艺,并在折射率和扩散组份有线性关系的假定下,研究了扩散方程的解,得到了球透镜折射率分布的数学表达式,最后介绍了测试结果:  $\Delta n = 0.034$ ,  $NA = 0.16$ ,  $A = 0.030\text{mm}^{-1}$ , 理论结果和实验数据一致性能好。本文还给出了塑料梯折球透镜的干涉照片和成像照片。

The paper described the technology for fabrication plastic gradient index lens, obtained the mathematical expression from the solution of diffusion equation under the supposition of linear relationship between the index and the dopants. The parameters of the lens are  $n = 0.034$ ,  $NA = 0.16$ ,  $A = 0.030\text{mm}^{-1}$ , and show a good coincidence with the theoretical results. The image and interference picture are also shown.

本文发表在《1989年光电子器件与集成技术年会论文集》, 1989年

## 大数值孔径自聚焦复合透镜面列阵研究

### A Study on Self-Focusing Planar Microlens Array with Large NA

刘德森 高应俊 章亚丽 阎国安

宋辉 姚胜利 高凤 孔庆芬

孔金荣 朱传贵 梅锁海

(中国科学院西安光学精密机械研究所)

本文讨论了在 PS-1 玻璃基片上制作自聚焦平面微透镜的工艺。由于窗口表面凸起,数值孔径可达 0.58。文中还从玻璃组成出发,从理论上分析了表面凸起的原因,得到的折射率增加量和实验值一致性很好。对窗口大小与折射率分布的关系也进行了较深入的分析,分析结果指出,窗口半径越小,凸起部分就易形成理想的球形表面,等折射率线愈接近半球形。最后介绍了我们制作的样品的光学性能,并对自聚焦复合透镜面列阵的应用进行了讨论。

A self focusing planar microlens array has been made on a glass substrate PS-1 by ion-exchanged technique, and because of the swelled structure near the window of the diffusion mask, the NA is as large as 0.58. The theoretical analysis on the properties of the microlens with swelled structure and the influence of the mask window size on the index distribution are given in this paper, and useful results are presented. At last we discussed the optical properties of the lens sample.

本文发表在《高速摄影与光子学》1990年及《吉林大学自然科学学报 1990年特刊》, 1990年

## 球对称折射率分布及其光程

### Spherical Gradients and the Optical Length

高应俊

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人们对变折射率问题的认识,首先是从球对称折射率渐变分布开始的。近几年来,球对称分布从仅仅具有理论分析的意义,渐渐地在实践中受到人们越来越多的注意。本文对球对称折射率分布作了进一步深入分析和研究,提出了一些深化了的更具体的认识,证明球对称分布中光线的倾斜度核心值即为其积分不变量,这在检验轴外光线的追迹结果时很有用。还证明了一种球对称分布透镜特例麦克斯韦透镜的任意共轭点之间的光程恒相等,与共轭点的选择无关,这是一个令人惊奇的结果。文中还给出了鲁尼伯格透镜内光线的光程。

Recently spherical gradients have received increased attention in the field of gradient-index optics. This paper explores some of the less known properties of rays in a spherical gradient. In the case of the Maxwell fisheye lens, a surprising result is that the optical path length between two conjugate points is not only the same for all rays joining the points, but is independent on the choice of the conjugate points

本文发表在《高速摄影与光子学》,1989年

## 两种离子交换型微透镜阵列

### Two Ion-Exchanged Microlens Arrays

高应俊 覃亚丽

(中国科学院西安光学精密机械研究所)

微透镜阵列可用许多方法如离子交换法,模铸法、等离子体气相沉积法、胶体共聚法、光敏胶法和光胶法等制作。本文得到掩盘式和开孔式两种离子交换工艺扩散方程的解析解,推导出掩盘式微透镜的最佳折射率分布,给出微透镜阵列的成像矩阵,制作出掩盘式平面微透镜阵列,并给出了其参数和成像照片。

Microlens array can be fabricated in many method, the ionexchanged, molding, plasma CVD, interfacial-gel copolymerising, photolytic and monolithic technique, and so on. The authors obtained analytic solutions of the diffusion equations for window ion-exchanged planar microlens array, derived the optimum index distribution for disk-mask microlens, gave the image matrix of microlens, fabricated the divergent disk-mask microlens array and showed the parameters and the picture taken with the array.

本文发表在“International Conference on Optoelectronic Science and Engineering”, Beijing, SPIE Vol 1230, 1990

### 从自聚焦透镜的发展到自聚 焦复合透镜面列阵的研制

#### Development of Gradient Index Lens and Research of Gradient Planar Microlens Array

刘德森

(中国科学院西安光学精密机械研究所)

本文对单个自聚焦透镜和自聚焦透镜阵列在制作工艺、光学特性方面的特点进行了较深入的分析和比较,最后提出,自聚焦复合透镜面列阵是自聚焦透镜的发展,它采用了光集成技术和离子交换工艺相结合的方法制作,这两种技术的结合形成了一种光刻电场辅助离子交换新工艺。自聚焦复合透镜面列阵的出现是分立元件向组合元件的发展,也是自聚焦透镜向光集成器件方向的发展,是一种新的微小光学器件和三维集成光学器件。

The paper analyzed the characteristics of fabrication and optical properties of gradient index singls lens and gradient index microlens array, and pointed out that the gradient index microlens array is a result of development of gradient index lens. The micro-lens array is fabricated by the optical integration technique and ion-exchanging process, the combination of this two method gives a new photoetching ion-exchange technique aided with electric field. The gradient index microlens array shows the development from discrete to composite devices, from gradient lens to integrated devices, which is a new micro-optics and three dimension integrated component.

本文发表在《1989年光电子器件与集成技术年会论文集》, 1989年

### 两种变折射率平面微透镜阵列

#### Two Gragient-Index Planar Microlens Array

高应俊 覃亚丽

(中国科学院西安光学精密机械研究所)

微透镜阵列是微小光学中的引人注目的器件。已有多种方法如离子交换法、模铸法、等离子体气相沉积法、胶体共聚法、光敏胶法和光胶法等用于微透镜阵列的制作,其中以离子交换法在理论和工艺上取得大的进展和好的结果。

本文提出两种离子交换型平面微透镜阵列, 给出了它们的定解扩散方程和定解条件, 得到了相应的解析解, 导出了掩盘式微透镜的成像矩阵和最佳折射率分布, 制作出掩盘式微透镜阵列, 并给出其成像照片和主要参数。

Micro lens array is a conspicuous device in micro-optics. There have been many methods to fabricate micro lens array, such as the ion-exchanged, molding, plasma CVD, interfacial gel copolymerising, photolytic, and monolithic techniques. Among them, the ion-exchanged process has achieved the better improvements and results in theory and practice.

The authors suggested the two kinds of ion-exchanged technique, window and disc-mask methods. The diffusion equations and the relevant initial and boundary conditions were determined and the solutions were given; the optimum index distribution for disc-mask micro lens was derived; the image matrix was shown. A divergent disc-mask micro lens array was fabricated in the first, and the parameters and the picture taken with the array are also shown.

本文发表在 The second microoptics conference / The eighth optical meeting on gradient-index optical imaging systems, Tokyo, July 24-26, 1989

### 变折射率棒折射率分布的干涉法无损自动测量

#### Automatic and Nondestructive Measurement of the Index Distribution of Gradient-Index Rods by a Interference Method

高应俊 李长乐

(中国科学院西安光学精密机械研究所)

组装了一种大口径马赫—曾特干涉系统, 采用加装了显微接口的摄像机作干涉图样的摄取、全画面快速光电转换装置, 经过模数转换系统, 送计算机作数据处理, 以绘图仪和打印机为输出装置。虽然采用低速模数转换器件, 整个系统可达到较高的处理速度, 约 12s 完成一幅干涉图样的自动处理和输出。

Composed a large aperture Mach-Zehnder interference system, and used a TV camera with a microscope interface to carry out opto-electric transformation in whole pattern rapidly. The data were A / D transformed and put in a microcomputer and treated, and lastly output on plotter and printer. A low speed A / D device was used, but a higher processing speed, about 12 second was achieved in the whole system.

本文发表在“第三届全国纤维光学与集成光学学术交流会”, 及《第二届全国光计算技术研讨会论文集》, 1988 年

## 变折射率光学研究中的几个问题

### Some Problems on Gradient Index Optical Study

刘德森

(中国科学院西安光学精密机械研究所)

变折射率光学是近十多年发展起来的应用光学的一门分支学科。本文摘要讨论了变折射率光学当前集中研究的几个重要问题。特别是对折射率分布, 成像特性和制作工艺方面的研究现状进行了较深入讨论。作者认为, 自聚焦透镜复合阵列研究是自聚焦透镜分立元件向组合元件的发展, 是一种新型微小光学元件, 是今后一种重要发展方向。

Gradient index optics, developed in recent ten more years, is a branch field in applied optics. The paper reviewed on the index distribution, optical path and image characteristics, aberrations, fabrication, typical applications and development trend for gradient index lens in detail, and especially presented that the planar gradient microlens array and intergrated element is one trend of development of gradient index lens.

本文发表在《特种玻璃》, 5, 1988 年

## 变折射率透镜研究和发展现状

### A Review on the Research and Development of Gradiend Index Lens

刘德森

(中国科学院西安光学精密机械研究所)

本文对变折射率透镜的折射率分布、光线轨迹和成像特性、变折射率透镜的像差、制作工艺、变折射率透镜的典型应用和变折射率透镜的研究动向进行了综合性、概括性的评论, 特别是提出了分布型折射率平面微透镜、集成光学元件是变折射率透镜今后的发展方向。

The paper reviewed on the index distribution, optical path and image chracteristics, aberrations, fabrication, typical applications, and development trend for gradient index lens in detail, and especially presented that the planar microlens array and integrated element is one trend of development of gradient index lens.

本文发表在《物理》, 17, 1988 年

## 单片 4 门集成 PLZT 尾纤光开关



## Single Chip PLZT 4-Gate

### Optical Switch with Pigtailed

曾庆济 段耀明 杜敏 叶爱伦

(上海交通大学)

本文报道了一种单片 4 门集成 PLZT 多模光纤光开关。该光开关具有平坦的谱特性, 在 700nm 的波长范围内, 消光比大于 27dB, 插入损耗小于 8.4dB; 脉冲驱动工作电压为 725V, 直流半波电压为 560V; 接通响应时间为 2.85 $\mu$ s, 关断响应时间为 0.27 $\mu$ s。该结果是目下文献所报道的室温下 PLZT 光开关中最快的。文章还对开关性能的进一步改进及其应用进行了讨论。

This paper reports a single chip PLZT 4-gate optical switch with multimode pigtailed. It has a flat wavelength characteristics. In the wavelength range of 700nm, extinction ratio of 27dB, insertion loss of 8.4dB have been obtained. The pulsed driving voltage is 725 volts, and the DC halfwave voltage is 560 volts. To our knowledge, the turn-on response time of 2.85 $\mu$ s and turn-off response time of 0.27 $\mu$ s are the best results in the room temperature among all the reported PLZT optical switches. In addition, the improvements and applications are discussed.

本文发表在 CLEO' 91, Baltimore, Maryland, USA

## 用于 InP / InGaAs(P) 的低温开管 Zn 扩散法

### Low Temperature Open Tube Zn Diffusion

in InP / InGaAs(P)

李维旦 潘慧珍

为了在 InP / InGaAs (P) 材料中进行精确的选择扩散, 同时又要保证外延生长的多层异质结构不被破坏, 提出了一种新的低温开管 Zn 扩散方法。该法直至在  $T = 500^{\circ}\text{C}$ ,  $t = 5\text{min}$  的条件下, 重复性仍很好。应用该法研究了低温条件下 Zn 在 InP, InGaAs (P) 材料中的扩散行为, 实验首次发现, Zn 在 InGaAsP 材料中的扩散速率与材料中 P 含量的平方成正比。

To fabricate quasi-planar optoelectronic integrated circuits (OEICs), a new open tube Zn diffusion method has been developed. The characteristics of Zn diffusion in InP / InGaAs(P) heterostructure materials at comparatively low temperature have been studied, and it has been found for the first time that Zn diffusion rate is proportional to the square of phosphorus content of the InGaAsP materials.

本文发表在 JOURNAL OF ELECTRONICS, VOL.5, NO.3, JULY, 1988

### 单片集成光发射器频率特性分析

#### Analysis for the Frequency Characteristics of a Monolithically Integrated Light Transmitter

李维旦\* 严志新\* 王晨\* 潘慧珍\*\*

(\* 中国科学院上海冶金所、\*\* 上海科技大学)

本文对 Tucker 等的激光二极管小信号模型作了改进, 进而用 SPICE 程序分析了由异质结晶体管 (HBT) 电路和激光二极管组成的单片集成光发射器的频率特性。通过分析, 提取了适合于目前常规工艺的优化参数, 并就此计算了优化后的 OEIC 频率特性。电路参数优化后的单片集成光发射器的频响接近单个 LD 的频响。

Tucker's small signal model for semiconductor laser diode has been improved so as to be used for the DC and AC analysis of the OEIC with SPICE program. Using this improved model, the monolithic integration of a heterojunction bipolar transistor driving circuit and a laser diode has been analysed. It has been shown that the base resistance  $R_b$  and the forward transit time  $t_f$  are the most important parameters of HBTs which affect the frequency characteristics of the OEIC seriously.

本文发表在《电子学报》第 2 期, 1989 年 3 月

### 用 Mn 作有源层将双集电区的 HBT 和边发射 LED 在准平面上集成

#### Quasi-planar Intergration of an InGaAsP / InP Double Collection Region HBT and an Edge-Emitting LED with Mn Doped Active Layer

李维旦 富小妹 潘慧珍

(中国科学院上海冶金研究所)

本文研究了 InGaAsP / InP 系光电子器件的准平面单片集成技术。采用 Mn 掺杂制作有源层, 选择性 Zn 扩散以及聚合物保护等工艺将双集电区的 HBT 和边发射 LED 集成在准平面结构上。制得的 OEIC 中 HBT 上升时间为 300ps,  $BV_{ceo}$  大于 8V, 其截止电压小于 30mV。

A monolithically intergrated InGaAsP / InP device including a HBT and E-LED was

fabricated with quasi-planar structure using Mn doped active layer and selective Zn diffusion as well as polyimide protection. 300ps rise time of the HBT was achieved together with  $BV_{ceo}$  larger than 8V and the offset voltage smaller than 30 mV.

本文发表在 JOURNAL OF ELECTRONICS, Vol.5, No.4, Oct.1988

## GRINSCH-AQW 激光器波导特性的数值分析

### Numerical Analyses of Waveguiding Properties

#### for GRINSCH-SQW Lasers

林 瑜 潘慧珍

(中国科学院上海冶金研究所)

采用折射率台阶近似法将梯度折射率分别限制异质结单量子阱 (GRINSCH-SQW) 激光器波导结构中的缓变折射率层离散成折射率近似为常数的亚层, 从而推导出此波导的近似本征方程, 并用数值计算求解出波导对于基模的等效折射率。在此基础上, 通过计算波导中垂直于激光器结平面方向上的光强近场分布, 计算出与激光器的阈值电流有密切关系的光学常数——激光器有源层的光限制因子  $\Gamma$  以及各种波导结构参数对  $\Gamma$  的影响, 同时计算了激光器的远场图形。计算结果可用于 GRINSCH-SQW 激光器波导结构参数的优化设计。

Step approximation of refractive index has been adopted to discrete the graded-index layer of GRINSCH-SQW Laser into many sublayers to obtain the eigenvalue equation of the waveguide. The effective refractive index of the fundamental mode has been calculated by using numerical method to solve the eigenvalue equation. By calculating the near-field optical intensity distribution in the direction perpendicular to the junction plane, we have calculated the optical confinement factor which is closely related to the threshold current density. Based on this, influence of the waveguide parameters on the optical confinement properties has been discussed.

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## 超薄异质结构材料 MOCVD 生长系统的设计与研制

### A MOCVD System for Growing Ultra-thin

#### Hetero-structure Material

陈 翔 潘慧珍

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本文报告了 OE-1 型 MOCVD 系统的研制工作。为精确控制各种的馈送量,从而生长出超薄异质结构外延层,我们选用了精确度达 0.5%,响应时间小于 2s 的模块式质量流量控制系统,各种源料的馈送可分别独立控制或按比例主从控制,并可用计算机对整个系统的工作状态进行遥控。在气路设计安装上尽可能提高气流稳定性,减小气路死角和使用特殊设计的组合阀门等,都是提高外延材料组份控制精度的有效措施。

An OE-1 type MOCVD system has been reported. A modular flow control system has been adopted whose accuracy and response time is 0.5% and less than 2 seconds respectively, so that ultra-thin heterostructure epitaxial layers can be grown with the accurate control on the feeds of various source substances. The individual flow control module is a versatile element that can be serve in a variety of ways, such as total flow control and master-slave control. The system can be remote controlled by computer. There are some effective ways improving the gas flow stability and reducing the dead corner with the use of specially designed valves.

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### 半导体激光器高速 GaAs 驱动电路

#### High Speed GaAs Driving Circuit for Semiconductor Lasers

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光通信与光互连中的高速调制需要有高速的驱动电路。本文设计并研制了 GaAs 高速驱动电路,采用差分电路作为高速电流开关来驱动激光器并采用标准的离子注入 GaAs IC 工艺,其中 MESFET 的栅长为  $1\mu\text{m}$ ,跨导约  $150\text{ms/mm}$ 。此电路可与激光器单片集成,制作单片集成的光电子回路。

A high speed driving circuit used to modulate a laser is desperately needed in optical communication and optical interconnection. A high speed GaAs driving circuit has been designed and fabricated with ion implantation and standard recessed gate process. Differential circuit is adopted as high speed current switch in this driving circuit. The gate length of MESFET is  $1\mu\text{m}$  and the transconductance is about  $150\text{ms/mm}$ . This circuit can be integrated monolithically with lasers to fabricate OEIC.

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## 改善 GRINSCH-SQW 波导光限制特性的计算

### The Calculation of Optical Confinement Characteristics of Modified GRINSCH-SQW Waveguides

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GRINSCH-SQW 激光器由于具有很低的阈值电流,因而广泛地应用于 OEIC 的制作中。本文从波导的光限制因子的角度出发,在 GRINSCH-SQW 波导光限制特性的分析基础上,对 GRINSCH-SQW 波导结构进行了改进,并计算了改进的 GRINSCH-SQW 波导光限制特性。结果表明,改进后的 GRINSCH-SQW 波导的光限制因子增加了 5%。

GRINSCH-SQW Lasers are widely used in OEICs for their very low threshold current. In this paper, based on the analysis of characteristics of optical confinement of GRINSCH-SQW waveguide, we modified the GRINSCH-SQW structure to improve its performance and then calculated its characteristics of optical confinement. The result indicated that the optical confinement factor has been improved about 5%.

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## 用于 InP 光电子集成器件的湿法腐蚀研究

### Study on Wet Etching Technique for InP Based Optoelectronic Devices

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InP 光电子集成器件的制作常需要采用不同要求的腐蚀工艺。为此,本文研究了三种不同的腐蚀剂对 InP/InGaAs 材料腐蚀特性。结果表明:  $\text{Br}_2\text{HBr}$ 、 $\text{HCl}$ 、 $\text{HNO}_3$  和  $\text{H}_2\text{SO}_4$ 、 $\text{H}_2\text{O}_2$  腐蚀液分别适用于隐埋外延前衬底制备、浅台面隔离和不同材料间的选择腐蚀。

Wet etching with different characteristics are very important techniques for the fabrication of optoelectronic devices. This technique includes: 1. groove etching for buried epitaxial growth, 2. graded step etching for isolation and 3. selective etching for different materials. Three different etchant systems.  $\text{Br}_2$ :  $\text{HBr}$ ,  $\text{HCl}:\text{HNO}_3$  and  $\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2$  systems have been studied for InGaAsP/InP system experimentally. The results show that these etchants are suitable for the mentioned usages in InP based optoelectronic devices and OEIC fabrication.

本文发表在“第五届全国集成光学学术讨论会”，上海，1989 年

### **InP 光发射 OEIC 中激光管的设计和研制**

#### **Design and Fabrication of Laser Diode for InP OEIC Transmitter**

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为了获得阈值较低、温度特性较好的长波长 InP 系激光管，器件采用了隐埋脊形结构。对漏电流密度的计算表明，此种结构较易实现对有源区电流的限制。另外，结构上的简化可以降低寄生电容，改善调制特性。工艺上采用 LPE 方法进行二次外延，与 HBT 工艺兼容。设计并研制上述激光管，为进一步研制单片集成的 LD/HBT OEIC 光发射机提供基础。

We have adopted a buried ridge structure to pursue a long-wave length InP laser diode which has a low threshold current and good temperature characteristics. It has been shown by the leakage current density computation that the BH structure helps to confine the current of active region. Besides, the symplification of the structure may lower the parasitic capacitance and improve the modulating characteristics. Two-step epitaxy process is realized by LPE, which is compatible with HBT processing. The mentioned laser diode has been designed and fabricated, which assures the future monolithical integration of the LD/HBT OEIC phototransmitter.

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### **用于高速系统的单片集成 InGaAs 光接收模块**

#### **Monolithically Integrated InGaAs Optical Receiver Module**

##### **for High Speed Systems**

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本文设计并研制了用于高速系统的单片集成 InGaAs 光接收模块。该模块将一个 PIN 光电探测器和一个跨导型的两级放大电路集成在一起，共 10 个器件，4 根引出线。由于大部分布线都在芯片内部完成，器件分布参数大大降低，有利于工作频率提高。根据模拟计算，该模块可用于 500Mb/s 以上的系统。

A monolithically integrated InGaAs optical receiver module for high speed systems

have been designed and fabricated. The module, containing ten devices and four leads, has integrated a PIN photodetector with a transconductance amplifier on a single chip. Since most of the connecting is realized in the chip, the parasitic reactance is greatly reduced and the working frequency can be raised. According to the analogous computation, this module can be applied to the systems above 500Mb/s.

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### 平面型 InGaAs PIN-JFET 单片集成光接收器研究 Monolithically Integrated Planar InGaAs PIN-JFET Optical Receiver

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研究了适用于 560Mb/s 以上光通信系统的全平面结构 InGaAs PIN-JFET 单片集成光接收器。采用 LPE 在掺 Fe 的半绝缘 InP 衬底上生长平面 InGaAs 外延层，JFET 的栅区和 PIN 光探测器的结区用选择 Be 离子注入进行 P 型掺杂。器件之间采用开管扩 Zn 新工艺进行 P-N 结隔离，P 岛间及 N 岛间击穿电压分别达 140V 与 200V；5V 偏置下漏电流分别小于 20nA 与 3nA。此种隔离技术可满足 PIN-JFET 平面化集成的要求。

A monolithically integrated planar InGaAs PIN-JFET optical receiver, which is suitable for above 500Mb/s optical communication systems, has been studied. The planar InGaAs epitaxial layer is grown on the Fe-doped semi-insulating InP substrate by LPE. The gate area of the JFETs and the junction area of the PIN photodetectors are P-type doped by selective ion implantation of Be. A new technique of open diffusion of Zn has been adopted to realize the P-N junction isolation between the devices on the chip. The break voltage between two P-islands and two N-islands are 140V and 200V, and the leakage currents under 5V bias are 20nA and 3nA respectively. These results indicate that the technique of isolation is suitable for planar integration of PIN-JFET.

本文发表在“1989年全国光电子器件与集成技术年会”，北京

### 光学互连用 GaAs 单片集成光接收器的设计及工艺研究 Study on GaAs Monolithically Integrated Receiver for Optical Interconnection

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对以 MSM-PD 为光探测器件, MESFET 为信号放大器件的 GaAs 单片集成光接收器的设计与关键制作工艺进行了研究。采用半绝缘 GaAs 衬底上 MBE 生长的两层结构外延材料制作集成器件。MSM-PD 为叉指型电极, 宽度  $2\mu\text{m}$ , 间隔  $4\mu\text{m}$ , 光敏区面积  $80 \times 80 \mu\text{m}^2$ , 在  $-5\text{V}$  偏置下暗电流小于  $10\text{nA}$ 。对集成光接收器的频率特性进行了计算, 为使频率响应达到  $1\text{Gb/s}$  以上, MESFET 的栅长定为  $1.5 \mu\text{m}$ , 栅源间距  $2 \mu\text{m}$ 。

The design and critical fabricating technique of monolithically integrated optical receiver, which adopted MSM-PD as its photodetector and MESFET as its signal amplifier, have been studied. The integrated chip is fabricated with a two-layer-structure epitaxial material grown on the semi-insulating GaAs substrate by MBE technique. For MSM-PD, the width and spacing of the interdigital electrodes are  $2 \mu\text{m}$  and  $4\mu\text{m}$  respectively. The photo-sensitive area is  $80 \times 80 \mu\text{m}^2$  and the dark current is less than  $10\text{nA}$  under  $-5\text{V}$  bias. According to the computation about frequency characteristics of integrated optical receiver, a gate length of  $1.5 \mu\text{m}$  and a gate-source spacing of  $2\mu\text{m}$  are adopted for a MESFET to assure the frequency response of  $1 \text{Gb/s}$  and above.

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## 准平面高增益 InGaAsP / InP(N-P-N)异质结双极晶体管

### Quasi-Planar High Gain InGaAsP / InP(N-P-N)

#### Heterostructure Bipolar Transistor

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异质双极晶体管(HBT)是制作光电子集成电路(OEIC)的理想电子器件之一。本文采用 Mn 作为 N-P-N InGaAs / InP HBT 的基区掺杂剂, 成功地抑制了 P-N 结与异质结在外延和器件工艺中发生的移位, 从而制得了适用于 OEIC 的高增益准平面 InGaAsP / InP HBT, 其  $h_{FE}$  达 880, 是该种结构 InGaAsP / InP 器件迄今报道的最高值。

Heterostructure bipolar transistor (HBT) is one of the ideal electronic devices for optoelectronic integrated circuit (OEIC). Mn has been adopted as a dopant for the base region of N-P-N InGaAsP / InP HBT, which successfully inhibited the displacement of p-n junction from the heterojunction in the process of epitaxy and device fabrication. A high gain quasi-planar InGaAsP / InP HBT is obtained. Its  $h_{FE}$  is as high as 880; That is



the highest value reported for device of such structure.

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### InGaAsP / InP NPN 异质结双极晶体管研究

#### A Analysis and Fabrication of InGaAsP / InP HBT

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从理论上分析了异质结双极晶体管的直交流特性，结合 CAA 技术进行了 InGaAsP / InP HBT 能带设计以及参数设计。利用液相外延研制出台面异质结双极晶体管。发射区材料为掺 Sn 的 InP ( $E_g=1.35\text{eV}$ )，基区材料为掺 Zn 的  $\text{In}_{0.73}\text{Ga}_{0.27}\text{As}_{0.60}\text{P}_{0.40}$  ( $E_g=0.95\text{eV}$ )。当基区宽度  $W_b=0.2\sim 0.3\mu\text{m}$ ,  $N_{ab}=(3\sim 5)\times 10^{17}/\text{cm}^3$  时， $h_{fe}$  最大为 760 ( $I_c=10\text{mA}$ ,  $V_{ce}=10\text{V}$ )，这是国内研究 InP 系 HBT 的最高值，且与国外发表数值接近。这一结果为 InP 系长波长光发射器单片集成提供了优良的电子器件。

With energy band design and parameter design by virtue of CAA technique, a NPN InGaAs / InP Heterojunction Bipolar Transistor(HBT) has been fabricated and analyzed using LPE. Sn-doped InP ( $E_g=1.35\text{eV}$ ) and Zn-doped InGaAsP ( $E_g=0.95\text{eV}$ ) is used as its emitter and base material respectively. The  $h_{fe}$  as high as 760 is obtained when base width is  $0.2\mu\text{m}$  and doping level is  $(3-5)\times 10^{17}/\text{cm}^3$ . This value is the highest in China till now and comparable to those reported in abroad. The result shows that BHT is a promising electronic device in the research of InP emitter OEIC.

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### Zn 扩散异质结双极晶体管

#### Fabrication of InGaAsP / InP HBT with Zn-Diffusion

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异质结双极晶体管由于与激光器结构相容，是 InP 系光发射集成单元研究的重要电子器件。我们用液相外延研制了 InP 系 HBT，并测试了直流特性。该晶体管采用台面结构，基区为掺 Zn 的 InGaAsP ( $\lambda=1.3\mu\text{m}$ )。为防止发射极 pn 结偏位，外延时发射区掺杂浓度略高于基区浓度。为了引出基极电极，采用 Zn 浅扩散，扩散温度  $500^\circ\text{C}$ 、 $10'$  左右，扩散深度  $0.5\mu\text{m}$ 。直流测试结果，共射极电流放大倍数 50 左右，输出电流  $40\sim$

50mA, 满足低  $I_{th}$  激光器驱动电流需要。

Due to its similar structure with DH-LDs, Heterojunction Bipolar Transistor(HBT) is an important device in emitter OEIC research. A mesa-structure NPN HBT with Zn-diffusion is fabricated using LPE and the static characteristics is measured. The doping of the emitter is a little higher than that of InGaAsP base to avoid Zn in the base diffusion into the emitter. And Zn shallow diffusion technique is needed to form the base electrode after the mesa is formed. The diffusion depth is about  $0.5\ \mu\text{m}$  with low diffusion temperature and short time( $500^\circ\text{C}$ ,  $10'$ ). The measured result shows that the  $h_{fe}$  of the HBT is about 50 under a current level 40–50mA, which is enough for driving a low threshold laser.

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### Be 离子注入 InGaAs PINFET 单片集成

#### InGaAs PINJFET Research with Be-ion Implantation

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为克服扩散的余误差分布在 pn 结处浓度梯度小, 不利用 JFET 跨导提高的弱点, 采用 Be 离子注入和快速退火技术研究了 InGaAs/InP PINJFET 接收单元。Be 注入用  $\text{Si}_3\text{N}_4$  掩蔽带胶注入, 能量 50KeV, 剂量  $2 \times 10^{14}\text{cm}^{-2}$ 。为防止 Be 在 InGaAs 中快速扩散, 采用高效感应炉内快速退火方法。

器件采用环形栅 FET, 在栅柄处制作 PIN PD 与栅极并联。PIN 面积  $40 \times 40\ \mu\text{m}^2$ , JFET 栅长  $3\ \mu\text{m}$ 、宽  $150\ \mu\text{m}$ , 测试结果跨导为  $20\text{ms/mm}$ 。

In order to overcome the disadvantage of low transconductance caused by Zn-diffusion, of which the carrier gradient is not steep enough, Be-ion implantation and transient annealing technique is used in the research of InGaAs OEIC PINJFETs. A layer of photoresist and  $\text{Si}_3\text{N}_4$  is needed when Be-ion is implanted with an energy of 50KeV,  $2 \times 10^{14}\text{cm}^{-2}$  dose. Transient annealing is necessary to avoid Be deep diffusion into the InGaAs layer.

A ring-shaped gate is used in the fabrication of JFETPIN, and a  $40 \times 40\ \mu\text{m}^2$  PIN-PD is connected to the handle of the JFET whose gate length is  $3\ \mu\text{m}$ . The measured transconductance is  $20\text{ms/mm}$ .

本文发表在《光电子器件与集成技术年会论文集》，1989年

## 异质结双极晶体管的计算机分析和优化设计

### HBT Characteristics Analysis and Optimization Design by Computer

杜宏霞 黄以明 李克诚

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以 Anderson 能带模型为基础, 采用 Schokly 漂移扩散理论, 并假设载流子分布满足波尔兹曼分布和小注入情况, 对 InP 系 HBT 中的各种复合机制、热电子效应、寄生二极管效应等对 HBT 直流交流特性影响进行了计算机模拟。结果表明, 异质结晶体管的复合主要取决于界面和空间电荷区复合; 而用等效扩散系数则可以表征热电子效应。这些结论为 HBT 制作提供了理论依据。在此基础上, 对 HBT 的  $f_T$ 、 $\beta$  等参数进行了优化设计。测试结果与计算结果相符。

The paper based on Anderson model, demonstrates the computer analysis for HBT using the Schokly drift-diffusion theory. Under small injection condition and Boltzman distribution assumption, various recombination mechanisms, hot electron effect, parasite diode effect are calculated with computer program. It is evident that surface recombination is not so serious as that of the interface recombination and space charge region recombination. And an effective diffusivity is used to describe the hot electron effect. The above results are important conclusions in fabrication of HBT. At last, an optimization program for the performance parameters, such as  $f_T$ 、 $\beta$  is given. The results are in agreement with the measured data of the device.

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## 五、光纤导波光学器件 Optical Wave Guide Devices

### 1.5 $\mu\text{m}$ x-切 y-向 Ti : LiNbO<sub>3</sub> 条形波导相位调制器

1.5 $\mu\text{m}$  x-cut and y-direction  
Ti : LiNbO<sub>3</sub> Strip Waveguide  
Phase Modulator

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用 x-切 y-向 Ti : LiNbO<sub>3</sub> 条形波导及其两侧非对称传输线电极, 研制出 1.5 $\mu\text{m}$  行波相位调制器。在线性工作点, 小信号调制的理论带宽为 8GHz。用低频技术测量器件的高频调制特性。在 2GHz 和 6GHz, 对器件进行了小信号调制。检测光探测器输出中的低频信号幅度随微波频率的变化, 由此确定调制带宽不小于 6GHz。

A 1.5 $\mu\text{m}$  traveling-Wave phase modulator has been developed by using x-cut and y-direction Ti : LiNbO<sub>3</sub> strip waveguide and asymmetric transmission line electrodes on two sides of one. At linearity operation point, 3dB theoretical bandwidth of small signal modulation is 8GHz. High frequency properties of the device have been measured using low frequency technique. At 2GHz and 6GHz, the device has been modulated using small signal. In output of light detector, low frequency signal amplitude variances as microwave frequency have been measured, and it is determined that modulation bandwidth is no less than 6GHz.

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### 1.5 $\mu\text{m}$ Ti : LiNbO<sub>3</sub> 电光波导强度调制器

1.5 $\mu\text{m}$  Ti : LiNbO<sub>3</sub> Electrooptic Waveguide Intensity Modulator

张伯华 高福斌 金 锋

(中国科学院长春物理研究所)

用钛内扩散技术和光刻手段, 研制出 1.5 $\mu\text{m}$  LiNbO<sub>3</sub> 电光波导强度调制器。它由单模波导非对称 Mach-Zehnder 干涉仪和三电极共平面波导组成。干涉仪的两臂长相差波导

波长的四分之一,使器件在最佳线性点上工作,无需外加偏压。集总调制和行波调制的理论带宽分别为 1GHz 和 7.8GHz。对于集总器件,测量了调制特性,半波电压为 9.5V,调制带宽为 0.7GHz。

A 1.5 $\mu\text{m}$ LiNbO<sub>3</sub> electrooptic waveguide intensity modulator has been developed by using Titanium indiffusion technique and photolithographic method. It consists of a single-mode waveguide asymmetric March-Zehnder interferometer and a three-electrode coplanar waveguide. Two arms of the interferometer are different in length by one quarter of a guide wavelength, allowing the device to operate at its optimal linearity point without external electrical bias. Theoretical bandwidths for lumped modulation and traveling-wave modulation are 1GHz and 7.8GHz. For the lumped device, modulation properties has been measured, its half-wave voltage is 9.5V, and modulation band-width is 0.7GHz.

本文发表在《高速摄影与光子学》,第 2 期,1990 年

### Z-切 Ti : LiNbO<sub>3</sub> 平面波导模式数量的色散特性

#### Dispersion Formulae of Total Number of Modes for the z-Cut

#### Ti : LiNbO<sub>3</sub> Planar Waveguides

金 锋 高福斌

(中国科学院长春物理研究所)

对于在流动干氩气氛中扩散而形成的 Z-切 Ti : LiNbO<sub>3</sub> 平面波导,用 Fouchet 等人提出的钛感应折射率增量在 0.6~1.6 $\mu\text{m}$  波长范围内的色散关系,推得与扩散参数有显函数关系的模式数量的色散关系。在若干重要波长,用这些色散公式,画出模式数量和扩散参数的关系曲线,可用来控制相应波导和器件的模式数量。

For the z-cut Ti : LiNbO<sub>3</sub> planar optical waveguides, diffused in a flowing atmosphere of dry argon, dispersion formulae of total number of modes as an apparent function of diffusion parameters have been derived using dispersion relations, presented by Fouchet et al, of Ti induced refractive index increment at a range of 0.6~1.6 $\mu\text{m}$  wavelength. At important several wavelength, total number curves of modes as a function of diffusion parameters have been plotted using these dispersion formulae, which can be used in control of total number of modes for corresponding waveguides and devices.

本文发表在《高速摄影与光子学》,第 4 期,1990 年

## Z-切 Ti : LiNbO<sub>3</sub> 平面波导模式数量的色散特性

### Dispersion Formulae of Total Number of Modes for the Z-cut Ti : LiNbO<sub>3</sub> Planar Waveguides

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For the Z-cut Ti : LiNbO<sub>3</sub> planar Optical waveguides, diffused in a flowing atmosphere of dry argon, dispersion formulae of total number of modes as an apparent function of diffusion parameters have been derived using dispersion relations, presented by Fouchet et al, of Ti induced refractive index increment at a range of 0.6~1.6 $\mu$ m wavelength. At important several wavelength, total number curves of modes as a function of diffusion parameters have been plotted using these dispersion formulae, which can be used in control of total number of modes for corresponding waveguides and devices.

本文发表在《高速摄影与光子学》, 第 4 期, 1990 年

## 1.5 $\mu$ m 切 y 向 Ti : LiNbO<sub>3</sub> 条形波导相位调制器

### 1.5 $\mu$ m x-cut and y-Direction Ti : LiNbO<sub>3</sub> Stripe Waveguide Phase Modulator

高福斌 金 锋 罗 达

史长青 孟淑华 李丽娜

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用 x 切 y 向 Ti : LiNbO<sub>3</sub> 条形波导及其两侧非对称传输线电极, 研制出 1.5 $\mu$ m 行波相位调制器。在线性工作点, 小信号调制的理论带宽为 8GHz。用低频技术测量器件的高频调制特性。在 2GHz 和 6GHz, 对器件进行了小信号调制。检测光探测器输出中的低频信号幅度随微波频率的变化, 由此确定调制带宽不小于 6GHz。

A 1.5 $\mu$ m traveling-wave phase modulator has been developed by using x-cut and y-direction Ti : LiNbO<sub>3</sub> stripe waveguide and asymmetric transmission line electrodes on two side of one. At linearity operation point, 3dB theoretical bandwidth of small signal modulation is 8GHz. High frequency properties of the device have been measured using

low frequency technique. At 2GHz and 6GHz, the device has been modulated using small signal. In output of light detector, low frequency signal amplitude variances as microwave frequency have been measured, and it is determined that modulation bandwidth is no less than 6GHz.

本文发表在“89 年(北京)光电子集成年会”

### **1.5 $\mu$ mTi : LiNbO<sub>3</sub> 电光波导强度调制器**

#### **1.5 $\mu$ mTi : LiNbO<sub>3</sub> Electrooptic Waveguide Intensity Modulator**

张伯华 高福斌 金 锋

(中国科学院长春物理研究所)

用钛内扩散技术和光刻手段, 研制出 1.5 $\mu$ mLiNbO<sub>3</sub> 电光波导强度调制器。它由单模波导非对称 Mach-Zhender 干涉仪和三电极共平面波导组成。干涉仪的两个臂长相差波导波长的四分之一, 使器件在最佳线性点上工作, 无需外加偏压。集总调制和行波调制的理论带宽分别为 1GHz 和 7.8GHz。对于集总器件, 测量了调制特性, 半波电压为 9.5V, 调制带宽为 0.7GHz。

A 1.5 $\mu$ m LiNbO<sub>3</sub> electrooptic waveguide intensity modulator has been developed by using titanium indiffusion technique and photolithographic method. It consists of a single-mode waveguide asymmetric Mach-Zhender interferometer and a three-electrode coplanar waveguide. Two arms of the interferometer are different in length by one quarter of a guide wavelength, allowing the device to operate at its optimal linearity point without external electrical bias. Theoretical bandwidths for lumped modulation and traveling-wave modulation are 1GHz and 7.8GHz. For the lumped device, modulation properties has been measured, its half-wave voltage is 9.5V, and modulation bandwidth is 0.7GHz.

本文发表在《高速摄影与光子学》, 第 2 期, 1990 年

### **一个简单光电集成回路的计算机辅助分析**

#### **Computer Aided Analysis of a Simple Optoelectronic Integrated Circuit**

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本文采用一适于光电集成回路 (OEIC) 的计算机辅助分析程序, 对含一个激光二极管 (LD)、两个金属半导体场效应晶体管 (MESFET) 的混合和单片 OEIC 做了较详细

的分析, 主要考虑: LD 的偏置情况  $I_0 / I_{th}$  (工作电流与阈值电流之比), 引线及封装产生的寄生参数对输出光的频率响应和小信号脉冲响应特性的影响, 结果表明: 寄生电阻, 小于 5pF 的寄生电容影响不大, 而 LD 的偏置情况, 寄生电感对回路的频响和小信号脉冲响应有极大影响。室温下, 该混合 OEIC 芯片, 当 LD 工作在二倍阈值以上, 引线寄生电阻和电感分别取为  $0.1\Omega$  和  $0.3nH$  时, 小信号调制带宽可达 4GHz, 由于单片集成极大地减小了寄生电感 (主要是引线电感), 因此, 单片集成在提高 OEIC 的工作速度上具有很大的优越性。

Using a computer aided analysis program for optoelectronic integrated circuit(OEIC), the small-signal modulation characteristics of hybrid and monolithic OEIC of a laser diode (LD) and two metal-semiconductor field effect transistors (MESFET) are analyzed. It is considered that the LD bias  $I_0 / I_{th}$  ( $I_0$  is the operation current,  $I_{th}$  is the threshold current) and the parasitic parameters of interconnecting wire and package affect on the frequency-response characteristic and the small-signal pulse response characteristic of laser output. The results show that the effect of the parasitic resistance and the capacitance under 5pF is not evident, but for the LD bias and parasitic inductance, the effect is very strong. At room temperature, when  $I_0 / I_{th}$  is larger than 2, and the resistance and inductance of interconnecting wire are  $0.1\Omega$  and  $0.3nH$ , respectively, the small-signal modulation band of the hybrid OEIC chip is as large as 4GHz. Because the monolithic OEIC decreases the parasitic inductance, it is useful on highspeed OEIC.

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### 适用于 GaAs 光发射机单片集成的宽接触 BH 激光器的研制

#### Fabrication of a Broad Contact BH Laser for Monolithic Integration

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(吉林大学)

利用在二次 LPE 生长中发现的伴生高阻限流层现象在 SI-GaAs 衬底上制成一种新型 BH 激光器。这种新器件制作简单、重复性好且与驱动电路的制作工艺兼容。在  $6 \sim 8\mu m$  有源条宽和  $250 \sim 300\mu m$  腔长下, 器件的 CW 阈值电流 (300K) 可低至 28mA, 线性输出光功率可达 11mW。

By using a partner high resistance confinement layer, a novel BH laser, with the advantages of simplified fabrication, considerable repetitiveness and processing-compatibility with the driver circuit, has been fabricated on SI-GaAs substrate. The CW (at 300K) threshold current of this device was as low as 28mA for  $4 \sim 6\mu m$  active stripe width and 250



~300 $\mu$ m cavity length, and the linear light output power was as high as 11mW.

本文发表在《1989 光电子器件与集成技术年会论文集》

### 宽带电光导波模数转换器概述

#### An Overview of Wide-Band Electrooptical Guided-Wave Analog-to-Digital Converters

李宝贞

(上海交通大学)

本文介绍了电光导波模数转换器的功能、发展与宽带模数转换器件在光参数与电参数上的要求。

该器件以脉冲激光作为信息载波,并对模拟信号进行光采样。它以 N 位并列的电光导波调制器阵列作为幅度分析器进行编码,再经数字输出电路使量化成为数字信号。光模数转换器的特性为精度(决定于调制器位数)适中而频带很宽,转换速度很快。要作到宽带则要求光采样频率高,调制器、检测器与数字输出电路的带宽够大。在光性能上则要求光取样速率、光脉冲宽度、光脉冲抖动时间与光功率都要满足一定条件,本文列出一些参考数据。

An optical A / D converter can be thought of as an integrated optical amplitude analyzer which is optically sampled and is followed by one channel of fast digital electronics for each bit. The task of an A / D converter is to convert analog signal voltages to digital codes of computing, information processing and control systems. Previous studies indicate that optical converters show promise for moderate bit resolution applications in the gigasample per second range for analog bandwidths. Some optical and electrical factors effecting the conversion characteristics are indicated for reference in this paper to design the device.

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### 电光导波模数 (A / D) 转换器集成光路的研制

#### Electro-Optic Analog-to-Digital Conversion Using Channel Waveguide Fabry-Perot Modulator Array

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(上海交通大学)

本文概述以 Fabry-Perot 干涉调制器阵列为核心结构的光学 A/D 转换器的依据与原理。光学 A/D 转换器包含脉冲激光源、N 位调制器阵列、模拟输入信号源、光电检测器、数字输出电路。当信号电压同时加在各调制电极时, 由于调制电极长度成倍的减少, 因而各位的半波电压成倍的加大, 形成由最低到最高有效位的 N 位二进制数字输出。A/D 转换器的 F-P 调制器结构有一些优点, 而且在工艺上还不是太困难的, 因而我们试制了这种集成光路, 并初步进行测试。

Several types of A/D converters which utilize EO device in LiNbO<sub>3</sub> have been demonstrated. We are now using a F-P modulator array as a trial-manufacture, since this device utilizes only straight channel waveguides, it should possess the inherent advantages of small substrate size, simple geometrical layout and low optical insertion loss. Although the demand for polishing the end faces of the substrate to sustain multiple reflection within the waveguide is very strict, it is nevertheless technically feasible in our laboratory. The integrate circuit set is undergone preliminary tests for conversion effect.

本文发表在《中国光学学会第四届集成光学学术交流会议论文集》, 成都, 1987 年 10 月

### 1.3~1.6 $\mu$ m 全硅光波导和全硅电光调制光开关的研制

#### Study of All-Silicon Waveguide and Electro-Optical Switch for 1.3~1.6 $\mu$ m wavelength

刘恩科 张声良 韩金萍 李国正  
(西安交通大学)

在重掺杂  $n^+ < 100 >$  硅衬底上生长的轻掺杂的硅外延层上, 经氧化、光刻、各向异性湿法腐蚀、侧面抛光等技术, 成功地制成了全硅 1.3~1.6 $\mu$ m 平面光波导、脊形光波导、Y 型和 2x2X 型光功率分支器。分别用 1.32 $\mu$ m InGaAsP 激光器和 1.52He-Ne 激光器发出的激光, 经端面耦合入光波导样品, 输出的光经放大后, 从红外变像管上明显观察到导波图像。设计并成功地制作了 BOA 结构的, 利用等离子体色散效应形成的 1.3~1.6 $\mu$ m 全硅 2x2 电光开关, 在国内首次实现了硅的电光调制。

The All-Silicon planar and ridge waveguides, optical power divider of Y-type and 2x2 X-type at 1.3-1.6 $\mu$ m have been fabricated through the techniques of oxidation, photolithograph, preferential wet chemical etching, and end polish in the lightly doped single crystal Si layer grown epitaxially on heavily doped Si substrates. The 1.32 and 1.52 $\mu$ m collimated light from the InGaAsP and He-Ne laser source respectively are coupled into the samples and the near field radiation pattern was focused on an infrared vidicon. The 1.3-1.6 $\mu$ m All-Silicon 2x2 electro-optic switches are designed and fabricated successfully

on  $n/n^+$  silicon epitaxial wafers by using BOA structure and the plasma dispersion effect. It is the first time realized the electro—optic modulation of Si in China.

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### YIG 波导中非共线光—静磁波相互作用

#### Noncollinear Magneto—Optical Interaction between Optical Waves and Magnetostatic Waves in YIG Waveguide

何华辉 苏 钧 冯则坤 欧阳嘉

(华中理工大学固体电子学系)

由 YIG 波导激励起的静磁波引起的光导波的衍射一直是近年来集成光学信息处理中一个非常有前途的课题。利用静磁波正向体波已实现了宽频带磁光相互作用。在理论上,通常用亚里夫耦合模理论来进行分析。本文根据微波技术中谐振腔的微扰理论,提出用微扰法来处理 YIG 波导静磁前向体波和光导波的磁光相互作用,同时考虑 Faraday 和 Cotton—Mount 效应,探索了模式转换规律。用此理论分析了由静磁波引起的光偏转特性,所得的结果与现有的实验一致。

Diffraction of guided optical waves by magnetostatic waves (MSW) excited in YIG waveguides has been a promising subject for integrated optical signal processing in recent years, and very large bandwidth noncollinear magneto—optic interaction with magnetostatic forward volume waves (MSFVW) has been realized. Traditionally, the relevant theoretical analyses are conducted with Yariv's coupled mode method. The present paper develops the theory of the noncollinear coplanar magneto—optical interaction between MSFVW and guided light in YIG waveguides with the perturbation method similar to the one used in microwave resonant cavity, and explores the regularity of mode conversion by taking account of both Faraday and Cotton—Mouton effects. The scanning characteristics of guided optical waves by MSW are also analyzed, and the theoretical calculation are agreement with the experimental results given by Young et al.

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### 用于磁—光波导特性研究的近红外平面光波导耦合系统

#### Infrared Planar Optical Waveguide Coupling System for Magneto—Optical Waveguide Characteristic Research

Waveguide Characteristic Research

吴康寅 欧阳嘉 苏 钧 何华辉  
(华中理工大学固体电子学系)

本文报导了我们设计用于磁—光波导特性研究的近红外平面光波导耦合系统, 讨论了设计中考虑的因素。在此系统中, 我们用  $1.15\mu\text{m}$  He—Ne 激光器作光源, 用金红石棱镜作光束耦合器, 近红外电视机用来观察磁光波导中传输模式。利用此系统我们成功地实现了光与磁光波导的耦合, 并测量了有关磁光波导参数。为了提高测量精度, 用一光束准直系统来减少光束发散角。最后, 我们给出了测量误差估算公式。

Infrared planar optical waveguide coupling system for magneto-optical waveguide characteristic research are presented. Some design consideration of system are discussed. In this system, a  $1.15\mu\text{m}$  He—Ne laser is used as light source, and two rutile prisms are used as light beam couplers. A special TV camera sensitive to the infrared light is employed to detect the output beam. By means of this system, the laser beam is coupled in and out of magneto-optical waveguide successfully and some magneto-optical parameters are measured. In order to improve measurement accuracy and achieve higher coupling efficiency, a optical beam expander is used to reduce divergent angle. At last, a formula for evaluating the measurement error is given.

本文发表在《国际光电技术会议论文集》

### 静磁正向体波—光相互作用的实验研究

#### Experimental Research on Optical Guided—Wave Interaction with Magnetostatic Forward Volume Waves (MSFVW)

冯则坤 苏 钧 欧阳嘉 周世昌 何华辉  
(华中理工大学固体电学系)

本文报导了在 YIG—GGG 波导上实现了非共线共平面光导波与静磁正向体波的相互作用。实验是在厚度约  $15\mu\text{m}$ , 长为  $12\text{mm}$ , 宽为  $6\text{mm}$  YIG 薄膜中进行的。其使用的波长为  $1.317\mu\text{m}$  (半导体激光器)。用相距为  $10\text{mm}$  金属指条作为激发和探测静磁波的换能器。通过端面耦合方式来激励 TM 和 TE 光导波模式, 并利用一对偏振器进行检测。当静磁正向体波频在  $4\text{GHz}\sim 4.15\text{GHz}$  变化直流磁场为  $3000\text{ Oe}$  时, 观察到了由 MSFVW 引起的模式转换及光束偏转。利用微扰方法, 对非共线共平面静磁波—光相互作用进行了理论分析。

Noncollinear coplanar guided optical waves interaction with magnetostatic forward volume waves (MSFVW) in YIG—GGG waveguide has been demonstrated. The experi-

ments were performed with YIG film about  $15\mu\text{m}$  thick, 12mm long, 6mm wide at a wavelength of  $1.317\mu\text{m}$ . A pair of parallel metallic stripe with a separation of 10 mm in between is used as transducer to excite and detect MSFVW. Excitation and detection of the TM and TE mode light waves were facilitated using a pair of crossed polarizers by edge coupling at the input and output end faces of the waveguide sample. The TM—TE mode conversion and light beam deflection induced by MSFVW were experimental observed as the frequency of the MSFVW was tuned from 3.70 GHz to 4.15 GHz while the DE magnetic field was fixed at 3000 Oe. The theory analysis of the noncollinear coplanar magneto-optical interaction between MSFVW and guided light in YIG—GGG waveguide with the perturbation method is given.

本文发表在《第七届全国磁学会议论文集》

### 静磁波在任意磁化方向有限宽 YIG 薄膜静磁波色散特性

#### Dispersion Characteristics of Magnetostatic Wave in YIG with Magnetized

#### in Arbitrary Directions

苏 钧 冯则坤 何华辉

(华中理工大学固体电子学系)

本文得出了静磁波在任意磁化方向有限宽度 YIG 薄膜色散特性。通过数字分析, 讨论了样品的宽度对三种模式 (静磁表面波, 静磁正向体波, 静磁反向体波) 以及其它静磁波模式的影响。结果表明有限宽对静磁正向体波色散特性影响强于对静磁表面波, 而且随着模式阶数的增加或宽度的减少, 低频限趋于增大。高阶宽度模式对静磁反向体波的色散特性影响可以不考虑。

The dispersion equation of magnetostatic waves (MSWs) in YIG with finite width magnetized in arbitrary directions is derived in the present paper. By the numerical analyses, the effects of sample width on the three pure modes (i.e. MSSW, MSFVW, MSVBW) and the other modes of MSW are explored. The results show that finite width affects the dispersion characteristics of magnetostatic forward volume wave (MSFVW) more strongly than those of magnetostatic surface wave (MSSW) and higher order modes of width can be neglected for magnetostatic backward volume wave (MSVBW).

本文发表在《第九届国际铁氧体会议论文集》

### 500MHz Ti:LiNbO<sub>3</sub>2×2 光开关 / 调制器

#### A Ti:LiNbO<sub>3</sub>2×2 optical switch / Modulator

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本文描述一种采用铬—金电极的 Ti:LiNbO<sub>3</sub>X 型 2×2 光开关 / 调制器。给出了该器件的设计参数, 工艺条件, 研制成功的带单模尾纤的器件性能为: 总插入损耗 < 8dB, 开关电压 < 10V, 串音 < -15dB,  $\lambda = 1.3\mu\text{m}$ 。本文还着重讨论了器件的高频特性, 测得器件的调制频率 > 500MHz。

A Ti:LiNbO<sub>3</sub>2×2 optical switch / Modulator with a Cr—Au electrode has been fabricated and tested. The switching voltage was 10V, the fiberdevice—fiber loss was 8dB, the extinction ratio was 15 dB, and the 3dB bandwidth was more than 500MHz.

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### 钛扩散 Ti:LiNbO<sub>3</sub>1×4 集成光开关

#### Ti:LiNbO<sub>3</sub>1×4 Integrated—Optical Switch

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从无间距方向耦合器型 2×2 光开关作为基本单元, 用三个基本单元组成 1×4 集成光开关已经研制成功。该 1×4 集成光开关工作波长为  $1.3\mu\text{m}$ , 每一单元的 ON / OFF 为 12.7~16.7dB, 开关电压为 18~23V; 每一对电极电容量为 6pF, 理论工作带宽为 1GHz。

A 1×4 optical switch array with 3 zero gap directional Couplers integrated on a LiNbO<sub>3</sub>Chip has been fabricated at  $\lambda = 1.3\mu\text{m}$ . The ON / OFF ratio, the switch voltage, the electrode capacitance, and the theoretical bandwidth are 12.7dB—16.7dB, 18V—23V, 6pF and 1GHz respectively.

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### InP—InGaAsP 异质结构定向耦合器设计

#### Design of InP—InGaAsP Heterostructure Directional Coupler

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长波长光通信所用光源为 InP-InGaAsP 激光器, 为了便于与之实现单片集成, 采用同一种材料设计制作定向耦合器, 就显得非常必要。定向耦合器一般是采用两个靠得很近的条波导组成; 条波导的结构将对器件的性能产生重大影响。各种条波导相比较, 以加载条形波导最适宜于构成定向耦合器, 我们选用了等效折射率法, 根据平面波传输可以等效为传输线传输的原理, 经过计算设计出定向耦合器。

In order to realize monolithic integration with InP-InGaAsP lasers in  $1.3\mu\text{m}$  and  $1.5\mu\text{m}$  optical communication systems, it is very important to adopt directional couplers made of InP-InGaAsP. The directional coupler consists of two stripe optical waveguide which are adjacent very closely. The structure of waveguide affects the characteristics of coupler. Compared with other kinds of waveguide, the strip-loaded waveguide is the most suitable waveguide for directional coupler. On the bases of equivalent refractive index method and by using the principle of plane wave propagation equivalent to transmission line, the design of directional coupler is given.

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### 加载条形波导传输特性的分析

#### The Analysis of Transmission Characteristics of Loaded Strip Waveguide

陈若滩 陈德昭

(北京邮电学院)

本文分析了加载条形波导的传输特性, 给出了场的近似解析表示式。分析方法在 Macatili 方法的基础之上加了一阶微扰项, 给出了同变分法同样精确的结果, 同数值法结果符合得很好。

This paper analysed the transmission characteristics of loaded strip waveguide, and showed the approximate equation of electromagnetic field. This method based on the method of Macatili, added a new item (item of disturbance) and gave the same result as that of differential method.

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### 加载条形波导定向耦合器耦合长度的分析

## The Analysis of Coupling Length of Directional Coupler with Loaded Strip Waveguide

陈若滩 陈德昭

(北京邮电学院)

定向耦合器是许多集成光电子器件的基础元件, 诸如光开关、调制器等都可由定向耦合器构成。

随着集成光学的迅速发展, 能够同半导体激光器等有源器件集成到一块芯片上的有源材料构成的调制器就愈来愈引起人们的重视, 同半导体激光器具有相似层次结构的加载条形波导调制器就显得更加重要。

本文分析了这种波导调制器的耦合长度, 给出了场的近似表达式。分析结果较等效折射率法给出的结果更为精确, 且具有简洁、明了的优点, 使我们很清楚的知道引入误差的地方, 因而对其精度能够心中有数。

The directional couplers are basic elements of many intergrated devices, for example optical switches and modulators can be composed by directional coupler.

With the rapid development of integrated optics, people put more and more attention to the modulators composed by active materials which can be integrated into one chip with active devices such as semiconductor laser. Modulators with loaded strip waveguides which have similar layer structure with semiconductor lasers seem to become more important.

Coupling length of such wavguide modulator is analysed and approximate equations of the electromagnetic field is shown in this paper. The result is more accurate than that given by refractory ratio method and this method is simple and easy. From it, we can clearly know where errors were introduced. So that we can estimate the accuracy.

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## 声光布拉格衍射偏转器的设计制作

### Design and Fabrication of Acoustooptic Bragg Diffraction Deflector

金国良 许政权 徐秦瑶

(上海交通大学)

设计并制作了中心频率在 215MHz、带宽为 50MHz 的声光布拉格衍射偏转器。在 X 切割、Y 向传播的铌酸锂波导表面上制作指条平行于 Y 向的叉指铝电极, 指条宽度  $4\mu\text{m}$ , 指条长 3mm, 指对数 7.5。铝电极用高频溅射方法制成。观察了不同激励频率下的声光衍射, 一级衍射光斑清晰, 无其他衍射级, 激励频率与衍射光斑位置一一对应。

An acoustooptic Bragg diffraction deflector with center frequency at 215MHz and bandwidth of 50MHz has been designed and fabricated. On the surface of x-cut y propa-



gating lithium niobate waveguide we prepared an interdigital aluminum poles, which fingers are parallel to Y direction, with finger width of  $4\mu\text{m}$ , the interaction length of 3mm, and finger pair number of 7.5. The acoustooptic diffraction at different exciting frequencies was observed. The first-order diffraction light spot is clear; there is no other diffraction order observed; and the exciting frequencies are corresponding to the positions of the light spots.

本文发表在《第五届全国集成光学学术讨论会论文集》

### 声光布拉格衍射偏转器的设计和制作

#### Design and fabrication of acoustooptical Bragg diffraction deflector

金国良 许政权 徐秦瑶

(上海交通大学)

本文从集成光学频谱分析仪的需要出发, 根据声光互作用的基本原理和结论, 设计了中心频率为 214MHz, 3dB 带宽为 50MHz 的布喇格衍射偏转器, 重点讨论了叉指换能器的各项参数选择。并且运用了传统集成电路的制作工艺做出了声光布喇格衍射偏转器, 测试了系统的频率响应特性曲线以及功率—衍射效率曲线, 得到了满足设计要求的结果。

To satisfy the demand of integrated optical spectrum analyzer, the acousto-optical Bragg diffraction deflector was designed according to the principle of acoustooptics. The center frequency of this system is 214MHz, 3dB bandwidth is 50MHz. The concerned parameters were discussed for the interdigital transducer, which is one of the main components in this system. The system has been fabricated using the IC fabrication technology. Its frequency response and the diffraction efficiency versus input power have been measured.

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### 玻璃光纤放大器特性

#### The Specific Property of Glass Fibre Amplifier

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本文考虑了掺稀土玻璃光纤放大器作为中继放大器在长距离光纤通讯中实行直接光—光放大的优点。研究了掺钕玻璃光纤放大器的荧光特性, 测出了其荧光光谱和荧光寿命,

并用中心波长为  $1.064\mu\text{m}$  及  $1.054\mu\text{m}$  激光束作为信号光源, 观察了它们的放大现象。前者得到可观的放大, 后者没有看到放大现象, 根据这些观察, 并结合荧光光谱的光强分布状况, 说明掺钕光纤放大器的线宽至少有  $30\mu\text{m}$ 。并说明掺铒光纤放大器的线宽至少为  $25\text{nm}$ 。

The advantage of direct light-light amplify using rare-earth-doped glass fibre as the repeater in long distant optical communication is considered. The fluorescent characteristic of the Nd-doped glass fibre amplifier is analysed, its fluorescent spectrum and fluorescent life-time are measured and the amplifying phenomena in the amplifier are observed using the  $1.064\mu\text{m}$  and  $1.054\mu\text{m}$  laser light as the signal. There is a considerable amplify in the  $1.064\mu\text{m}$  region, but no amplifying effect in the  $1.054\mu\text{m}$  region. Based on these observation and the intensity distribution in the fluorescent spectrum, we conclude that the linewidth of the Nd-doped fibre amplifier is at least  $30\text{nm}$  and that of the Er-doped fibre amplifier is at least  $25\text{nm}$ .

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### 掺钕单模光纤激光器

#### Nd-Doped Single-Mode Fibre Laser

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研究了低损耗掺钕单模玻璃光纤中激光发射条件。光纤两端面镀介质膜, 介质膜对激光波长 ( $1.08\mu\text{m}$ ) 具有高反射率 (98%), 构成全封闭式的法布里-伯罗共振腔。用氩激光 ( $\lambda=514.5\text{nm}$ ) 做泵浦光源。

在氩激光连续泵浦的情况下, 研究了激光输出特性, 观察了激光模的花样和光强分布。研究了激光阈值  $P_{\text{th}}$  与光纤和泵浦光特性及钕离子参数的关系, 这可用下式表示:

$$P_{\text{th}} = (h\nu_p / \sigma_e \tau_2) (\delta_0 / 2) A (\eta_p / F)$$

其中  $\nu_p$  为泵浦光频率,  $\sigma_e$  及  $\tau_2$  分别为钕离子有效受激发射截面及亚稳态寿命,  $\delta_0$  是腔的损耗,  $A$  是纤芯面积,  $\eta_p / F$  与光纤的芯径和  $V$  值有关。

由上式算出的激光吸收阈值 ( $0.978\text{mW}$ ) 与实验值 ( $1.1\text{mW}$ ) 相当一致。

在脉冲泵浦的情况下, 看到一系列按阻尼衰减的激光脉冲尖峰, 表明光纤激光器处于单模弛豫振荡状态。

The lasing condition in low-loss Nd-doped single mode glass fibre is analysed. The two end surfaces of the fibre were coated with dielectric films having a high reflectivity ( $R=98\%$ ) at laser wavelength ( $1.08\mu\text{m}$ ), and a closed Fabry-Perot oscillating cavity was

formed. The pump source used was Ar-laser.

In cw-pumped case the laser output characteristic are studied, the output intensity distribution and the pattern of the output modes are observed. The dependence of the laser oscillation threshold  $P_{th}$  on the characteristics of fibre and pump source and the parameter of the  $Nd^{+3}$  is analysed.

It can be written as:

$$P_{th} = (h\nu_p / \sigma_e \tau_2)(\delta_o / 2)A(\eta_p / F)$$

Where  $\nu_p$  is the pumping light frequency,  $\sigma_e$  and  $\tau_2$  are the effective stimulated cross section and the metastable state lifetime of  $Nd^{+3}$  respectively,  $\delta_o$  is the loss of the cavity,  $A$  is the area of the fibre core,  $\eta_p / F$  has relation with the core diameter and the V-value of the fibre. The calculated value (0.978mW) using the above formula is in good agreement with the experimental result (1.1mW).

A series of laser pulsed spikes in the form of damped oscillation were observed under pulsed pumping. This indicate that the fibre laser was in the single mode relaxation oscillation region.

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## 定向耦合器光波导开关阵列研究

### Research on Directional Coupler Optical Waveguide Switch Array

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(上海交通大学)

本文讨论了三种类型的电光开关，着重论述了 Ti 扩散  $LiNbO_3$  定向耦合器型电光开关的原理和交替  $\Delta\beta$  方法。对  $4 \times 4$  定向耦合器型电光开关阵列的设计作了多方面的考虑。在 Z 切  $LiNbO_3$  衬底上制作了 Ti 扩散定向耦合器电光开关阵列。在自己设计的管座上固定光纤，完成光纤—器件—光纤的  $2 \times 2$  阵列。器件的工作波长为  $1.3\mu m$ 。

Three kinds of electrooptical switches are discussed in this paper, especially the principle of Ti diffused  $LiNbO_3$  directional coupler switch and alternating  $\Delta\beta$  method are mentioned in detail. The design of  $4 \times 4$  directional coupler switch array is taken into consideration in many ways. The fabrication of Ti diffused directional coupler switch array are carried out on z-cut  $LiNbO_3$  substrate. By attaching optical fiber to self-designed base, the  $2 \times 2$  fiber-device-fiber arrays have been completed. The wavelength for the device is  $1.3\mu m$ .

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## LiNbO<sub>3</sub> 光波导开关阵列的损耗分析

### Analyses for the loss of LiNbO<sub>3</sub> Optical Waveguide Switch Array

沈启舜 龚小成 应再生 邱伟

(上海交通大学)

把光纤耦合到 LiNbO<sub>3</sub> 光波导开关阵列, 构成光纤-器件-光纤, 以达到实用化, 须尽量降低整个器件的插入损耗。整个器件的损耗主要有四部分: 波导的传输损耗、费涅尔反射、光纤和波导的对准以及光纤和波导的横场尺寸匹配。其中, 传输损耗可以通过合理的设计、制作以及选择高质量的 LiNbO<sub>3</sub> 基片得到解决。使用折射率匹配液或抗反射膜可使费涅尔反射损失降到最小。于是, 主要考虑降低后二种损耗。用二种方法对准光纤和波导。一种是逐根对接法, 对光纤数较多的阵列调节维数太多, 耗时太长。另一种是自对准方法, 用 V 槽和光刻工艺把六维调节转化成一维调节, 在大阵列的对准中有其优越性。另一方面, 仔细选择扩散条件, 包括选择 Ti 厚度、扩散时间、扩散温度、Ti 条宽度等以达到横场匹配。通过上述各种改进, 测试结果, 整个器件的插入损耗大大降低。

It is essential to reduce the insertion loss for the practical switch array with optical fiber attaching to LiNbO<sub>3</sub> optical waveguide switch array. The insertion loss of the whole device is composed of four components: the propagation loss, Fresnel reflection, the fiber-waveguide mis-alignment and mode size mismatch. Among these, the propagation loss can be minimized by some methods, such as proper design, fabrication and choosing LiNbO<sub>3</sub> substrate with high quality. The Fresnel loss can also be minimized by using index-match liquid or AR coating. Thus, the later two components should be considered primarily. There are two methods for fiber-wave guide alignment. One is to attach fiber for waveguide one by one. The dimension for adjustment is too much for arrays with more fibers. The other is self-alignment method. By using V groove and photolithography technology, adjustment can be converted from b-D to 1-D. It is convenient for arrays with more fibers. Besides, in order to match mode size, it is necessary to choose diffused condition, such as the thickness of Ti strip, diffused time and temperature, the width of Ti stripe etc. With the improvement mentioned above, the insertion loss of the whole devices is reduced rapidly.

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## 扩 Ti: LiNbO<sub>3</sub> 光波导开关阵列的设计与制作

### Design and Fabrication for Optical Waveguide Switch Array with Ti diffused LiNbO<sub>3</sub> Substrate

龚小成 李建林 应再生 宋伯泉 陈益新  
(上海交通大学)

采用二电极  $\Delta\beta$  反转定向耦合器结构。为了尽可能降低开关电压, 须得到器件的最佳耦合长度。用 6 组不同的相互作用长度:  $L=5、6、7、8、9、10$  (mm), 从实践中获取最佳耦合长度。整个器件长度为 40mm, 最小线宽为  $4\mu\text{m}$ 。采用 Z 切  $\text{LiNbO}_3$  晶片, 用提浮法和高频溅射 Ti 膜制得 Ti 条图形。扩散温度  $950\sim 1050^\circ\text{C}$ , 时间  $5\sim 7\text{h}$ 。扩散后表面溅射  $\text{SiO}_2$  作为缓冲层, 经端面抛光、制作电极、压焊引线, 用单模光纤耦合进行测试, 从实验中求得定向耦合器的最佳耦合长度, 从而确定  $4\times 4$  光开关阵列的结构。

The directional coupler switch with two section reversed  $\Delta\beta$  structure is used. In order to reduce the switch voltage as low as possible, optimum coupling length should be achieved. In practice, six different interaction length:  $L=5、6、7、8、9、10$ (mm) is used to choose the optimum coupling length. The size of the device is 40mm, and the minimum line width is  $4\mu\text{m}$ . Ti waveguide pattern is obtained by using sputtering Ti and lift-off technology on z-cut  $\text{LiNbO}_3$ . The diffused temperature is  $950\sim 1050^\circ\text{C}$  and the diffused time is about  $5\sim 7$ hours. The buffer layer  $\text{SiO}_2$  is sputtered after diffusion. Then polish the terminal surface of the waveguide fabricale electrodes and weld the leads. Coupling the single mode fiber to waveguide to measure the parameters of the device, the optimum coupling length for the directional coupler switch is obtained and then the  $4\times 4$  optical switch array structure can be decided.

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### **$\text{LiNbO}_3$ 中 Ti / Mg 双扩散隐埋波导的研制**

#### **Research on Buried Optical Waveguide with Ti / Mg Double Diffusion Method on $\text{LiNbO}_3$ Substrate**

龚小成 马继勇 陈益新  
(上海交通大学)

扩 Ti: $\text{LiNbO}_3$  波导其折射率分布是非对称的。波导纵向深度仅  $1\sim 2\mu\text{m}$ 。当用光纤-波导耦合时效率很低。采用 Ti / Mg 双扩散, 利用 Mg 扩散入  $\text{LiNbO}_3$  可使折射率降低, 且不附加传输损耗, 使波导层埋入  $\text{LiNbO}_3$  中, 构成隐性埋波导, 其折射率分布接近对称, 大大提高光纤耦合效率。在常规扩 Ti: $\text{LiNbO}_3$  波导上溅射厚 25nm 的  $\text{MgO}$ , 在  $900^\circ\text{C}$  下浅扩散 3h。用波长为 632.8nm 的激光测试, 其近场图形显示光波导中光强分布有较好的对称性, 光纤-波导耦合效率也有明显提高。Ti / Mg 双扩散方法可用于各种扩

Ti:LiNbO<sub>3</sub> 波导器件中以降低插入损耗。

The depth index profile for Ti-diffused LiNbO<sub>3</sub> waveguide is asymmetric. The longitudinal depth of waveguide is only 1~2μm. The efficiency is rather poor while coupling fiber to waveguide. By using Ti/Mg double diffusion, the refractive index will be decreased after Mg ions diffused into Ti-diffused LiNbO<sub>3</sub> and the waveguide will be buried in LiNbO<sub>3</sub>, no additional propagation loss appeared. For this buried waveguide, the index profile should result in near symmetry and the fiber coupling efficiency will be increased. Waveguides fabrication were carried out by sputtering MgO with thickness 25nm on the conventional Ti-diffused LiNbO<sub>3</sub> waveguide and diffusing shallowly for 3 hours at 900°C. The near-field pattern was measured at 632.8nm wave length. The results shows that the asymmetry of the light intensity profile in the waveguide is improved and the fiber-waveguide coupling efficiency is increased clearly. Ti/Mg double diffusion can be used for a lot of Ti-diffused LiNbO<sub>3</sub> waveguide devices to reduce insertion loss.

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## BOA 型偏振无关光开关

### A Novel BOA Type Polarization Independent Optical Switch

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在 Z 切 LiNbO<sub>3</sub> 衬底上制做 BOA 型光波导开关，再套刻两组调制电极，其中一组由三块电极组成，另一组由两块电极组成。在第一组电极上加电压  $V_1$ ,  $V_2$  在第二组上加电压，即可构成一个光开关。在恰当的  $V_1, V_2, V_3$  的配合下便可实现偏振无关的开关效果。实验结果表明在不超过 50V 的开关电压下，可以实现偏振无关的开关效果。两路间的串话低于 21dB、工作波长为 1.3μm。

Polarization independent optical-waveguide devices are played an essential role in various applications of integrated optics. In this paper we propose a new model of BOA type polarization independent 2X2 optical waveguide switch, based on Z-cut LiNbO<sub>3</sub> substrate. It possesses a novel three-piece electrode system, which is easy to be fabricated and has never been seen before. The device still keeps the advantage of low loss on Z-cut LiNbO<sub>3</sub>, but has higher switching voltage is compared with that on X-cut.

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## 高速 $\text{LiNbO}_3$ 电光相位调制器

### High Speed $\text{LiNbO}_3$ Electrooptical Phase Modulator

吴伯瑜 李丽华 李德杰 应嘉年 邵晓风 彭吉虎

(清华大学)

以行波共面微带线作为调制电极系统, 设计了 6GHz 带宽行波电光相位调制器, 单模光波导用 Ti 扩散在 Z 切、X 切, Y 传  $\text{LiNbO}_3$  晶体上制成。采用工艺为: Ti 膜宽  $9\mu\text{m}$ , 厚 90nm, 在  $1050^\circ\text{C}$  湿氧气氛中扩散 9h。电极以电镀金加厚  $3\mu\text{m}$ 。用 HP8410C 型微波网络分析仪, 在  $f=0.5\text{--}6\text{GHz}$  上测得  $S_{11} < -8.24\text{dB}$ ,  $S_{21} < 9\text{dB}$ 。用扫描 F-P 干涉仪测量了它的相位调制系数, 频率响应, 器件的 3dB 带宽达到 6GHz, 激励功率为 0.5W 时, 在 7.5GHz 下仍有 0.575rad 的调制系数。

We designed 6GHz bandwidth travelling wave E-O phase modulator with coplanary stripline. The optical waveguide is fabricated in the surface of Z-cut and X-cut, Y propagation  $\text{LiNbO}_3$  substrate. The technology parameters are  $9\mu\text{m}$  width and 90nm thickness of Ti film, Ti diffusion is processed at  $1050^\circ\text{C}$  in wet  $\text{O}_2$  atmosphere for 9h, and gold electrode is electroplated, its thickness is of about  $3\mu\text{m}$ . The performance of microwave electrode system is measured in HP8410c microwave analyser. The  $S_{11}$  and  $S_{12}$  is less than  $-8.25\text{dB}$ ,  $9\text{dB}$  respectively. The frequency response of the devices is measured by scanning F-P interferometer. The 3dB bandwidth of the device is more than 6GHz, and its modulation indexes is of 0.575rad at 7.5 GHz with 0.5w microwave drive power.

本文发表在《1989 光电子器件与集成技术年会论文集》, 第 174 页

## 光交换机用开关阵的研究

### Study of switch Array for Photonic Exchange System

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(清华大学)

本文涉及时分光子交换系统中的  $\text{Ti:LiNbO}_3$  开关阵的设计、制造和测量。该开关阵由三个定向耦合器开关组成, 每个开关阵长度为 6mm (大约两个耦合长度)。我们测量了带尾光纤的包装好的器件性能, 串音小于  $-30\text{dB}$ , 插入损耗小于  $-13.9\text{dB}$ , 而开关电压不大于 30V。

This paper involves the design fabrication and measurement of  $1 \times 4$   $\text{Li:LiNbO}_3$  switch array applied in time-division photonic exchange systems. The switch array is composed of three directional coupler switches whose length is 6mm (about two coupling lengths). The

packaged devices with tail fibers are measured. The crosstalk is less than  $-30\text{dB}$ , insert loss is  $-13.9\text{dB}$ , and the switching voltages are no more than  $30\text{V}$ .

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### 影响 GaAs-GaAlAs 相位调制器的相位移效率因素的研究

#### Study on Phase Shift Efficiency of GaAs-GaAlAs Modulator

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本文报道的器件是利用薄波导层的耗尽边进行传输，并对器件加反向偏压造成折射指数很大改变的原理来制备的。也就是说，不仅利用了线性电光效应，还利用了电折射效应等。这种腐蚀脊型 GaAs-GaAlAs 双异质结结构的相位调制器，达到了迄今最高相位移效率的结果—— $69^\circ / \text{V} \cdot \text{mm}$ 。

通过反向偏压、测试光源波长和波导层载流子浓度对相位移效率的影响的研究，可以看出，在  $1.06\mu\text{m}$  测试光源波长时，GaAs-GaAlAs 相位调制器的 TE 模或 TM 模、相位移都随反向偏压的增加而线性地增加。文中指出，无论 TE 模或 TM 模的相位移效率均受波长影响，在接近波导层禁带宽度的波长光源下测试，可以得到最大相位移效率。在波导层载流子浓度  $4-5 \times 10^{17} \text{cm}^{-3}$  时，可得到最高的相位移效率。

The etching ridge GaAs-GaAlAs DH phase modulators are reported. The reverse-biased voltage, the wavelength of optical sources and carrier concentration dependence of phase modulator on phase shifting efficiency of the devices are studied. The largest phase shifting efficiency ever reported in a reverse-biased p-n junction is observed.

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### 波导损耗测量的一种新技术

#### A New Technique for Waveguide Loss Measurement

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采用一种新型的光传输损耗测量技术，即利用选行扫描方法来检测不同长度样品光信号的变化，可简单、快速、准确地测出波导的传输损耗。

此方法采用截断样品方法，但不用去除衬底中透过的光信号，只需将扫描信号选在波导信号最强点上即可测出信号的变化情况，借助瞬态波形存储仪和记录仪记下变化的信



号, 具有较好的重复性。用光功率计测量输出端不同的光功率变化, 算出传输损耗以核对上述结果, 可使两者得到较好的一致。

采用此测量方法, 不仅可以测量 InGaAs / InP 体系材料制成的光波导, 还可测量其他材料制成的光波导, 只是选用的光源和接收器波长不同而已。

The propagation losses in InGaAsP waveguide were measured using a new technique of TV line-selection. By this technique, the measurement can be made simply, quickly and accurately. It also can be used to measure the waveguide loss in other waveguide made by different material.

本文发表在《第五届全国集成光学学术讨论会论文集》

### 半导体相位调制器调制带宽的测试

#### Bandwidth Measurement of Semiconductor Phase Modulator

吴长川 吴学海 邬祥生

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本文阐述了半导体相位调制器带宽的定义及其测试原理、测试系统及测试结果。

在保持直流偏压和调制信号功率不变时, 增加调制频率使相移因子减小至低频的  $1/2$  的调制频率定义为半导体相位调制器的调制带宽。测试系统由光源、聚光系统、共焦扫描干涉仪、接受器及显示器组成。经器件调制的光由扫描干涉仪频谱分析, 并由显示器显示出各阶边带高度  $I_0 I_1$  等。

在  $\sigma < \pi/2$  时, 由  $(J_1 J_2$  各为一阶、零阶贝塞尔函数)  $I_1 / I_0 = J_1^2(\delta) / J_0^2(\delta) = \delta^2 / 4$

可测得相位移因子  $\delta$ , 进而可得带宽。运用该法测得 60MHz InGaAsP / InP 相位调制器的各阶边带及  $\delta$ 。

从测试情况看, 上述测试法操作方便、可靠, 是半导体相位调制器带宽测试的好方法。

In this paper, bandwidth measurement of semiconductor phase modulator using Fabry-Perot interferometer has been discussed. Details of measurement of bandwidth of InGaAsP / InP phase modulator are reported.

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### 相干选行法测试半导体调制器的相位移效率

#### Evaluation of Phase Shift Efficiency for Semiconductor Phase Modulators

## by Interference and TV Line-Selection

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本文报道利用 Mach-Zhender 干涉光路、光学显微镜和电视选行系统进行器件相位移效率测量的原理、基本装置以及对 GaAs 和 InP 半导体相位调制器的测量。

将器件置于 Mach-Zhender 干涉仪的一个臂上,并使该臂的光束耦合入波导,由此形成的两臂干涉条纹用红外摄像机接收。调制电压变化  $\Delta V_B$  时,条纹移动  $\Delta S$ ,通过电视选行系统将移动量和条纹间距  $D$  记录在 x-y 记录仪上。器件相位移效率  $\eta$  为 ( $L$  为器件电极长度)

$$\eta = 2\pi\Delta S / D\Delta V_B L$$

运用上述方法对 GaAs 和 InP 相位调制器相位移效率进行了测试,其结果表明该测试法和系统具有直观、可记录和可靠性高等特点,促进了器件研究的开展。

In this paper, we present the principles, facilities and some results of phase shift efficiency measurements for GaAs and InP phase modulators with Mach-Zhender Interferometer, microscope system and TV line-selector.

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## 影响半导体相位调制器带宽因素的研究

## Study on Factors Affecting the Bandwidth of Semiconductor Phase Modulator

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本文简要阐述了驻波半导体相位调制器的特点,分析了 RC 时间常数、阻抗失配以及引线参数影响器件带宽的重要因素,并着重研究了 RC 常数的影响。

旁路电容严重地增加了该时间常数,使 InGaAsP / InP 半导体相位调制器的实测带宽低于 60MHz,初步减小该电容使实测带宽提高至 160MHz。进一步减小该电容值,使之能忽略不计,并使带宽继续提高。其表达为

$$f_0 = 1 / 20\pi(R_s + R_1)C_1$$

其中  $C_1 R_1$  分别为结电容及与之串连的器件电阻,  $R_s$  为信号源内阻。根据该式,采用适当的器件结构与材料以减小  $R_1$  和  $C_1$ , 可将带宽提高至 1GHz 以上。

In this paper, we briefly discuss the characteristics of the lump-constant semiconductor phase modulators and deduce that the main restrictions on the bandwidth of the device are RC time constant, mismatch and parasite parameters of the transmission

line. The main stress is laid on the first one.

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### 掩埋式梯折型玻璃光波导研究

#### Study on the Buried Gradient

#### Index Glass Waveguide

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本文讨论了光刻和电场辅助下两阶段离子交换法制作玻璃光波导的新工艺, 这种工艺制作的光波导具有掩埋式、聚焦型的新特点。并详细介绍了我们利用拉普拉斯方法和有限差分法, 研究了一维和二维变边界条件下, 外场辅助下扩散方程的解, 理论分析和试验数据符合很好。

The paper described a new technique in fabricating glass waveguide. Photoetching and two-step ion exchanged aided with electric field were used. The fabricated waveguide is buried and index graded. The solutions of diffusion equation in the one and two dimension variable boundary conditions are studied. The theoretical analysis is good with the experiment data.

本文发表在《高速摄影与光子学》1990 年, 及《1989 年光电子器件与集成技术年会论文集》, 1989 年

### 真星型光纤耦合器

#### True Star Fibre-Optic Coupler

曾庆济 段耀明 叶爱伦

(上海交通大学)

S—K 式真星型 (RS 型) 光纤耦合器不仅具有全向出光, 单纤双向传输特点, 且易于扩展构造多级大容量光纤耦合网。作为关键部件, 本文提出了在线光纤环境的概念, 并报道了我们试制的多模 8 端口 RS 型耦合器的性能及其应用。

S—K true star (RS) fibre-optic coupler has the advantages of not only equal outputs in all directions and single fibre bidirectional transportation, but being easily extended to construct large dimension fibre-optic networks as well. As a key component, we propose

the concept of fibre-optic loop mirror, and report a multimode 8 port RS optical coupler together with its performance and application in this paper.

本文发表在《第五届全国光纤通信学术会议论文集》

### 宽带声光布拉格偏转器的研制

#### Design and fabrication of wide Bandwidth Acoustooptic Bragg Diffraction Deflector

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(上海交通大学)

本文采用两个倾斜的叉指换能器结构, 设计 100MHz 带宽的声光布拉格衍射偏转器。偏转器的中心频率为 170MHz。两叉指电极的指对数为 4.5, 中心频率分别为 145MHz 和 210MHz, 互作用长度分别为 5.6mm 和 2.7mm, 倾斜角为  $0.2^\circ$ , 间距 16mm。

实验观察到清晰的一级衍射斑, 没有其他衍射级。衍射斑与射频频率一一对应。实测 3dB 带宽为 119MHz。

In this paper we designed an acoustooptic Bragg diffraction deflector with the bandwidth of 100 MHz, utilizing the two-tilted-transducer structure. The center frequency of the deflector is 170 MHz. The finger pair number of both inter digital poles is 4.5, and the center frequencies of the transducers are 145 MHz and 210 MHz, and the interaction lengths are 5.6mm and 2.7mm, respectively. The inclination and the distance between two transducers are  $0.2^\circ$  and 16mm respectively.

In the experiment, the first-order diffraction light spot was clearly seen and no other-order diffraction spot could be seen. The diffraction light spot corresponded to the RF frequency. The measured 3 dB bandwidth was 119 MHz.

本文发表在《吉林大学自然科学学报 1990 年特刊》, 1990 年

### GaAs 波导相位调制器的研制

#### GaAs Waveguide Phase Modulator

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(浙江大学)

GaAs 材料是有源材料。GaAs 光波导器件可与激光器, 探测器, 微电子器件单片集

成, 并且有温度特性好, 抗辐射能力强, 易于规模生产等优点, 已成为集成光学领域的主要材料之一。本文报导了我们研制的 GaAs  $n^-/n^+$  材料波导相位调制器, 波导损耗为 5dB/cm 左右, 半波电压小于 15V。

GaAs a kind of active material, has been one of primary materials in the area of Integrated Optics. GaAs optical waveguide device can be integrated with laser, photodiode and other microelectronic devices. It has good temperature performance, strong anti-radiation ability and easiness of scale production, this paper reports the research and fabrication of GaAs  $n^-/n^+$  waveguide phase modulator with waveguide loss about 5 dB/cm and  $\pi$  phase shift voltage less than 15V.

本文发表在《全国光纤陀螺学术研讨会论文集》, 1990 年 10 月

### 单模脊型波导模场分布的近似计算

#### Approximate calculation for Field Distribution of Single-Mode Rib Waveguide

周黎明 杨佐娅 王明华

(浙江大学)

单模波导在长距离光通信和集成光学中具有极广泛的用途。在波导器件设计中, 分析计算波导的损耗, 波导与光纤耦合的效率, 电光波导调制器的调制效率等问题时, 都涉及波导中的模场分布。本文运用有效折射率方法推导了单模脊型波导模场分布的高斯近似表达式, 并给出一些应用实例。

Single-mode waveguide has a widespread usage in long distance optic communication and integrated optics. The field distribution in waveguide is always involved when loss of waveguide couple efficiency between waveguide and optic fiber and modulation efficiency of an electro-optic waveguide modulator etc. are analysed and calculated in the design of waveguide device. This paper deduces Gauss approximate formula of field distribution of rib waveguide, and takes some examples for application.

本文发表在《光电子器件与集成技术年会论文集》, 1989 年

### GaAs Mach-Zehnder 干涉型电光波导调制器的分析与设计

#### Analysis and Design for GaAs Mach-Zehnder Interferential Electro-Optic Waveguide Modulator

王明华 周黎明 杨佐娅  
(浙江大学)

高速低调制电压低损耗的电光波导调制器是高速光通信, 光信号处理系统中的重要元件。马赫-泽德尔干涉型电光波导强度调制器调制效率高, 调制电压低, 是一种性能优良的调制器结构。本文报导了我们对 GaAs 干涉型电光波导调制器的理论分析, 器件结构的设计, 主要制作工艺和部分测试结果。

Electro-optic waveguide modulator of high frequency, low driving voltage and low loss is important device in Optical communication and optic signal processing system. Mach-Zehnder interferential electro-optic waveguide modulator, with high modulation frequency and low driving voltage, has a good performing structure. This paper reports theorial analysis of the device, design on the structure main fabrication process and a part of results tested.

本文发表在“光电子器件与集成技术年会论文集”, 1989 年

### GaAs 对称定向耦合光开关

#### Symmetric Directional Coupler Optical Switch in GaAs

吴志武 王明华  
(浙江大学)

光开关是集成光学中的重要部件。本文提出了 GaAs 同质结对称耦合光波导开关及肖特基电极的分析与设计技术, 以及适用于我们提出的器件结构的设计思想和制作工艺, 特别提出了提高对称性的掩膜设计技术。

Optical switch is an important components in integrated optics. In this paper we present the GaAs homostructure symmetric waveguide switch and electrode directional switch with Schotky contact has been analyzed and fabricated, applicable to our experimental structure design thought and fabrication process. Provides a new design of waveguide structure on GaAs by using transitional deposition technique which limited the asymmetry caused by misregistration.

本文发表在“第一届国际光束传输学术讨论会论文集”, 1989 年 5 月

### 低损耗 Y-分支 GaAs / GaAlAs 异质结波导相位调制器的研究

## Low-loss Y-branch Phase Modulator of GaAs / GaAlAs Heterostructure

冯 浩 王明华

(浙江大学)

低损耗 Y-分支 GaAs 波导型相位调制器是国内急需的集成光学器件之一。由于 Y 型分支具有不受波长限制的特点。我们从理论上研究并制作了带有两个相位调制器的 Y 分支集成光学器件。脊型波导是用湿法刻蚀技术完成的。并从理论上分析、计算了它的损耗特性。

Y-branch two phase modulators have been researched and fabricated with a GaAs / GaAlAs heterostructure. Rid waveguide were fabricated by wet-etching techniques. Then reflecting loss of GaAs material was analyzed.

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## 一种结构新颖的 AlGaAs / GaAs

### OEIC 光发射机

#### A Novel AlGaAs / GaAs OEIC Transmitter

胡礼中 苏士昌 金恩顺

张淑芝 刘式慵 高鼎三

(吉林大学)

巧妙利用二次 LPE 生长中的伴生高阻层，设计并制成国内第一种单片集成光发射机——AlGaAs / GaAs PHRCL-BH LD / LPEC-MESFETs OEIC 光发射机。这种新器件由一个 BH LD 和两个 MESFET 构成。初步测量结果表明，此种器件至少具有 215MHz 的 3dB 调制带宽。

A partner-high-resistance-layer phenomenon observed in two-step LPE was ingeniously used to design and fabricate the first monolithic integrated transmitter in our country——AlGaAs / GaAs PHRCL-BH LD / LPEC-MESFETs OEIC transmitter, which was composed of a BH LD and two MESFETs. The preliminary measurement has shown that the 3dB modulation bandwidth of this new device was at least 215MHz.

本文发表在《吉林大学自然科学学报》，1990 年特刊

## 光波导二维近场分布的测量系统

### System for Measuring Z- dimension Field Distribution in Optical Waveguide With Near Field Method

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大多数实用化光波导场分布无法用理论方法精确计算。为研究波导光纤耦合, 控制波导制作工艺及设计, 检验功能器件, 必须借用实验方法测量光波导中二维场分布。我们采用逐点机械扫描的方法, 简单、测量动态范围大、测量面上均匀性好。系统由微机、步进电机带动的二维调节架、Si-APD, Ge-APD 光探测器、锁相放大器、光成像系统、成像监视器、激光源功率监测器等部分组成。实验结果将  $8\mu\text{m}$  波导面放大到  $3\text{mm}$  左右, 测量点  $30 \times 30$  个, 每点光功率动态范围可达  $40\text{dB}$ 。工作波长范围为  $0.5\text{--}1.65\mu\text{m}$ 。

Most of the optical waveguide field distribution can not be calculated exactly in theory. Measuring system for 2-D optical waveguide must be established in technological design, coupling research and final device test. We selected the way of mechanical scan by point and point which is simple, well-distributed and wide dynamic range. the system consists of microcomputer, step- motor driving 2D adjuster, Si- APD, Ge- APD photodetector, lock-in amplifier, photo-image system, image monitor and laser source power monitor. The result is that by amplifying  $8\mu\text{m}$  waveguide endface to  $3\text{mm}$ , testing  $30 \times 30$  points, the dynamic range of every point is upto  $40\text{dB}$ . The testing wavelength is  $0.5 \sim 1.65\mu\text{m}$ .

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## 单模光纤与 $\text{Ti:LiNbO}_3$

### 单模平面波导端面耦合的研究

### Study of End-Fire Coupling of Single Mode Fiber to $\text{Ti: LiNbO}_3$ Single Mode Waveguide

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根据模式耦合分析, 设计制作了一个实用的单模光纤与单模  $\text{Ti:LiNbO}_3$  平面波导端面激励装置。用电弧放电烧熔法在单模光纤端面制作了一个微透镜, 并采用 2 维的硅 V 形槽作为光纤与波导耦合的精密调节架。实验测得该耦合装置耦合效率为  $64\%$ 。

According to the mode coupling analysis, an available device used to the end-fire coup-



ling of single mode fiber to  $\text{Ti}:\text{LiNbO}_3$

Single mode waveguide was designed and fabricated. A microlens on the fiber end was formed by arc discharge, and a two dimensional silicon V-groove was used as the position alignment frame between fiber and waveguide. The coupling efficiency measured is up to 64%.

本文发表在《吉林大学自然科学学报》，1990 年特刊

## Ti 离子注入 $\text{LiNbO}_3$ 光波导

### Ti Ions Implanted Optical Waveguides in $\text{LiNbO}_3$

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对于实现集成光学器件，离子注入是一有用的方法。我们用这一方法在 Y—切  $\text{LiNbO}_3$  晶体上制造了平面光波导。对两组晶体进行了 Ti 离子注入，剂量分别为  $1 \times 10^{15}$  离子 /  $\text{cm}^2$ ，360KeV 和  $1 \times 10^{15}$  离子 /  $\text{cm}^2$ —2.260KeV。注入的样品分别在 200℃ 和 1000℃ 下退火 1 小时。在 6.328nm 激光束下，看到了单模光波导的传输。用背散射沟道谱对样品进行了分析，经 1000℃ 退火，消除了晶体的辐照损伤。

Ion implantation is useful method for forming the devices of integrated optics. We used this method to fabricate the planar optical waveguides on the Y—cut  $\text{LiNbO}_3$  plate. The two sample were implanted by  $1 \times 10^{15}$  ions /  $\text{cm}^2$  of Ti ions at 360 KeV and  $1 \times 10^{15}$  ions /  $\text{cm}^2$  of Tions at 260kev. Implanted samples were processed in one h at 200℃ and 1000℃ annealing temperature, respectively. The single mode optical waveguides for laser light of 632.8nm wavelength were obtained. The samples were analysed with RBS spectra. It shows that the radiation damage of crystal is eliminated at 1000℃ annealing temperature.

本文发表在《1989 年光电子器件与集成技术年会论文集》

## 二次多项式折射率分布平面光波导的模式

### Modes in Planar Optical Waveguide

### with Index Profile of Second Order Polynomial

范俊清

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本文对折射率分布为二次多项式的平面光波导，求解了 Holmboltz 方程，推得以抛物柱形函数表示的波导模式场分布精确解和模方程。这些结果可用于  $\text{Ag}^+$  或 K 离子交换

玻璃波导的有关问题研究。

For the planar optical waveguide with index profile of second order polynomial, the Holmhoitz equation is solved, and the exact solution of mode field profile and mode equation are derived in terms of parabolic—cylindrical function. The results can be used to deal with the relevant problems to the glass waveguide fabricated by  $\text{Ag}^+$  or  $\text{K}^+$  ion exchange technique.

本文发表在《光学学报》，第9卷，第2期，135~139页，1989年

### 大面积 $\text{Ti}:\text{LiNbO}_3$ 光波导与多次扩散研究

#### Study of Optical Waveguides with $50 \times 20\text{mm}^2$ and Multiple Diffusion

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研制大面积 ( $52 \times 20\text{mm}^2$ ) Ti 扩散  $\text{LiNbO}_3$  光波导，由于各种原因容易出现缺陷。其关键因素是衬底材料的不均匀，表面各处抛光的差异，及待扩散 Ti 膜厚度的不均等。实验证明一些缺陷可以用局部或全部重新蒸发 Ti 和再次扩散的方法修复。我们测量了多次扩散样品的 TE 模析射率分布，其结果与正常扩散光波导析射率分布不同，其分布为指数函数。同时，也注意到由于多次扩散引起了传输模式及传输损耗的改变。

The defects of Ti-diffused  $\text{LiNbO}_3$  optical waveguide with large area can be caused by a variety of reasons. The key factor is poor uniformity of  $\text{LiNbO}_3$  substrate and thickness inhomogeneous diffused Ti film etc. It is demonstrated by experiment that these defects is perfectible using Ti re-evaporation and multiple diffusion methods. We have measured the distribution of refractive indices in the modified samples. The result is different from the distribution normal waveguide and it can be expressed in an exponential. We would notice that some change of the propagation mode and loss have occurred by multiple diffusion.

本文发表在《吉林大学自然科学学报》，1990年特刊

### 导波声光 Bragg 调制器的研制

#### Study of Guided —Wave Acoustooptic Bragg Modulators

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我们设计和制作了用于集成光学频谱分析仪的导波声光 Bragg 调制器。这种器件是在单模钛扩散 Y—切  $\text{LiNbO}_3$  光波导上完成的。使用 632.8nm He—Ne 激光作光源, 用  $\text{TiO}_2$  直角棱镜耦合导波光。测出了器件的特性参数, 中心频率为 125MHz, 带宽为 50MHz。当在中心频率输入电功率为 120mW 时衍射效率接近 100%。

A guided-wave acoustooptic Bragg modulator has been designed and fabricated, for the application of IOSA. It achieved in a single-mode Ti—diffused Y—cut  $\text{LiNbO}_3$  waveguide. The  $\text{TiO}_2$  rutile prism was used to couple a He—Ne laser beam at 632.8nm into a guided beam. The device parameters were measured. The center frequency is 125MHz, the resultant bandwidth is 50 MHz when using the center frequency of 125MHz, the device has the diffraction efficiency near 100% of 125mw driving power.

本文发表在《1989 光电子器件与集成技术年会论文集》

### 硼离子注入石英玻璃光波导

#### Optical Waveguides of Fused Quartz by Boron—Ion Implantation

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本文报导在熔融石英衬底上用硼离子注入制造低损耗单模波导的结果。注入离子能量和剂量分别是 360keV 和  $3 \times 10^{15}$  离子 /  $\text{cm}^2$ 。发现波导仅维持单 TE 和 TM 模。测量了有效折射率  $N_e$  和  $N_m$ 。在我们的实验中, 沿波导深度方向的注入离子浓度和折射率分布是高斯分布。

A result for fabricating fused quartz waveguides by boron ion implantation is reported. The implanted ion energy and dosage are 360 keV and  $3 \times 10^{15}$  ion /  $\text{cm}^2$ , respectively. It was found that the waveguide only supports single TE and TM guide modes. The effective refractive indices  $N_e$  and  $N_m$  of modes were measured. In our experiments, the implanted ion concentration and index profile along the direction of waveguide depth are Gaussian distribution.

本文发表在《吉林大学自然科学报》, 1990 年特刊

### 非线性导波光栅的研究

#### The Research of Nonlinear Guided—wave Gratings

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薄膜光波导是实现非线性光学效应的理想结构形式。它提供了一维或二维无衍射光传播,把光束截面限制在光波长尺寸范围内,造成波导内激光功率密度成数量级增长,使非线性相互作用在低激光功耗下产生。

周期结构(光栅)在非线性导波中有着特别重要意义。由于非线性媒质有效折射率与耦合进波导的光功率密度有关,在导波矢量与光栅矢量匹配耦合情况下,可在波导中传输最大光强,当改变入射激光功率时,破坏了原来的最佳匹配耦合条件使耦合效率降低,甚至完全失配而阻断波导中光波传输。

本文描述非线性导波周期结构的基本概念和制备方法,并在 InSb 和 SDG 波导上制备出了光栅耦合器,实验观测到了非线性耦合效应,讨论了它们的实用化前景。

Thin film optical waveguides are ideal structure format to realize nonlinear optical effects. It provides one (or two)-dimension diffractless light wave transmission and limits laser beam cross-section within wavelength size, as a result the laser power density in the waveguide can be increased orders of magnitude. Such an increase of power density means nonlinear interaction can be produced in lower laser power loss.

Periodic structure (grating) is of momentous significance. Because effective refractive index of nonlinear media is related to the laser power density corpled into waveguide, maximum intensity can be transmitted in the waveguide under the matcehing coupling between vectors of guided weve and grating. As incident laser power is changed, optimum matching coupling conditions of waveguide are destroyed, corling efficiency is decreased, even guided wave is stoped. Fundamental coucept and fabricating method on nonlinear guided wave pe-riodic structure were described in this paper. And grating couplers were made on InSb and SDG waveguide. Nonlinear coupling effects were observed by experiments. Their practicabilities were discussed.

本文发表在《光学学报》,第10期,1990年

### 掺半导体玻璃 (SDG) 波导的导波功率限制

#### Power Limit of Guided Wave on Semiconductor-Doped Glass Waveguide

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首次制备出长 1cm 宽  $4\mu\text{m}$  的 SDG 沟道波导,通过与两端相连的抛物耦合喇叭实现了 1mm 激光束斑与沟道波导间的孔径匹配耦合以减少散射损耗,倍频 YAG 激光脉冲(波长 532nm)被光栅耦合器耦合进沟道波导再由棱镜耦合器从波导中耦合出来。当入射

激光脉冲能量约  $12\mu\text{J}$  时, 输出能量呈现非线性拐点, 约  $20\mu\text{J}$  时, 能量降至极小, 与国外报道的 SDG 平面波导相比, 非线性拐点移向更低阈值, 这是由于沟道波导对光的二维限制引起的。

基于 SDG 的超快时间响应特性和沟道波导对光的限制作用, 可设计各种高速全光波导开关器件, 可望在超快信号处理与光计算技术中得到广泛应用。

The channel waveguide (length of 1 cm and width of  $4\mu\text{m}$ ) were fabricated on SDG for the first time. Aperture match coupling between the 1mm laser beam spot and channel waveguide was realized by parabolic coupling horns connected with both ends of channel waveguide to decrease scattering loss. Double frequency YAG laser pulses ( $\lambda=532\text{nm}$ ) were coupled into the channel waveguide by grating coupler and coupled out waveguide by prism coupler. when incident laser pulse energy was about  $12\mu\text{J}$ , nonlinear turning point of output energy from waveguide was appeared. And output energy was fallen in minimum at about  $20\mu\text{J}$ . Comparing with SDG planner waveguide been repored by now, nonlinear turning point is shifed to lower threshold due to the two-dimension limitation of channel waveguide geometry.

In riew of ultrafast response characteristic of SDG and optical limit effect of channel waveguide, various high-speed all-optic waveguide switch devices can be designed and expected to apply field of ultrafast signal processing and optical calculating widely.

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### 在离子交换波导中的非线性棱镜耦合和功率限制

#### Nonlinear Prism Coupling and Power Limiting in Ion-Exchanged Waveguides

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我们首次报导了掺  $\text{CdS}_x\text{Se}_{1-x}$  玻璃离子交换波导中的非线性棱镜耦合、功率限制和模场变化。在棱镜耦合中, 非线性起点的阈值功率是 20mw, 输入功率为 60mw 时, 产生功率限制。这是目前报导的最低数值。我们还首次提出对接耦合条形波导的功率限制, 证明了热效应起决定作用。

We report results of nonlinear prism coupling, power limiting, and for the first time, observation of the mode field variation in ion-exchanged waveguides in a  $\text{CdS}_x\text{Se}_{1-x}$  doped glass. In the prism coupler, the threshold power for the onset of nonlinearity is 20mw and power limiting occurs at 60mw input power. This is the lowest value reported thus far. We

present for the first time power limiting in butt-coupled channel waveguides and convincingly evidence that the effect is dominated by thermal contribution.

本文发表在“Topical meeting on integrated and guided-wave optics”, 1988 Technical Digest Series, Vol.5, pp. 180-183, 1988

### 波导中的热非线性吸收和功率限制

#### Thermal Nonlinear Absorption and Power Limiting in Waveguides

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根据热效应解释了半导体掺杂玻璃波导中的功率限制。从测量的热相关的折射率和透过率是光波长的函数表明, 吸收系数的变化是由于高功率下加热大块玻璃衬底造成了波导的非线性性质。计算的平板波导的功率限制与测得的结果非常相近。我们还首先报导了大块玻璃衬底的光谱透过率与温度的关系曲线。这些数据对于解释文献报导的波导热非线性是有用的。

Power limiting in semiconductor-doped glass waveguides in the cw regime is explained on the basis of thermal effects. From the measurement of the temperature dependence of the refractive index and transmission as a function of wavelength, we show that the change in the absorption coefficient that is due to heating of the bulk-glass substrates at high optical powers accounts for the nonlinear behaviour of the waveguides. The power limiting observed in planar waveguides was calculated, and excellent agreement with experiment was obtained. We also report the first measurement to our knowledge of the temperature and spectral dependence of the refractive index of a bulk-glass substrate. These data are useful in interpreting thermal nonlinear effects in the waveguides reported in the literature.

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## 六、光计算算法及器件 Optical Computing Algorithm and Related Device

### 四种相关的分辨本领比较

#### Comparison of Discrimination Capabilities of Four Types of Correlation

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本文引入了两个参数来评价匹配滤波算法的分辨本领。针对某个字体的 26 个英文大写字母和 10 个阿拉伯数字, 分别给出了几种相关所对应的两个分辨本领参数值和 Horner 效率值。结果表明: 第一类微分相关的分辨本领最好, 但 Horner 效率低, 仅为 11.768% (对字母 O) 和 9.498% (对字母 G); 第二类微分相关的 Horner 效率为 25.028% (对字母 O) 和 22.869% (对字母 G)。

Two parameters are introduced to evaluate the discrimination capability of a matched filtering algorithm. With twenty six English capital letters and ten Arabic numbers in a certain typeface made and chosen to be a series of inputs, the values of two parameters and Horner efficiency, are present, respectively. Those results show that the first differentiation correlation has the best discrimination capability, and its Horner efficiency is low, 11.768% as to reference "O" and 9.498% as to reference "G". The Horner efficiency of the second differentiation correlation is 25.028% as to "O" and 22.869% as to "G".

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### 非相干光实现的二维复数离散傅里叶变换及其等效 4f 系统

#### Incoherent Optical Implementation of 2-D Complex Discrete Fourier Transform and Equivalent 4f System

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本文提出了用非相干光进行复数编码实现二维离散傅里叶变换 (DFT)。设计了一个多成像系统, 它可充分利用光学先天的并行处理的性能, 使得一个二维输入数据可以被同时处理。选择二维数据的像元数为  $6 \times 6$  并对此算法进行了验证。光学实验的结果和计算机模拟研究的结果相符。基于上述的结果, 研究了复数滤波和逆离散傅里叶变换

(IDFT), 用一个三单元等效 4f 系统就可实现非相干光的图像滤波。

A method is proposed in this paper using incoherent light with complex coding to realize 2-D discrete Fourier transform (DFT). A multi-imaging system is set up, which fully uses the inherent property of optical parallel processing. 2-D input data can be processed simultaneously. 2-D input data of  $N=6$  is chosen to verify the method. The experimental results accord well with computer simulated results. On this basis, complex filtering and inverse Fourier transform (IDFT) are also discussed. So an equivalent 4-f system with the three parts is built, which can be used in image filtering in incoherent optics.

本文发表在 Opt. Commun. Vol. 74, No. 5, p. 295, 1990

### 一维微分相关的旋转和尺度敏感性 Rotation and Scale Sensitivities of One-Dimensional Differentiation Correlation

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(中国科学院上海光学精密机械研究所)

用对称和非对称输入图形研究了一维微分相关的旋转和尺度敏感性。计算机模拟研究表明, 一维微分相关具有很好的旋转和尺度敏感性能, 几乎和仅相位滤波器的性能一样。

Both symmetrical and nonsymmetrical input patterns are used to study the rotation and scale sensitivities of 1-D differentiation correlation. Computer simulation results show that 1-D differentiation correlation has a good performance of rotation and scale sensitivities, almost the same as phase-only matched filter.

本文发表在 Opt. Commun. Vol. 75, No. 3,4, p. 219, 1990

### 基于 SBN: Ce 电控光束耦合的光致折变空间光调制 Photorefractive Spatial Light Modulation by Electrocontrolled Beam Coupling in SBN: Ce Crystals

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基于 SBN: Ce 晶体的电控双光束耦合效应和耦合增益的像空间调制, 本文提出了动态非相干的像转换, 改变外加电场可取得正或负的相干像复制。



Dynamic incoherent-to-coherent image conversion is proposed, which is based on the effects of electrocontrolled two-beam coupling in SBN: Ce and image spatial modulation of coupling gain. Either negative or positive coherent replica is obtained by altering the electric field. Analysis of the performance is made by coupled-wave theory, which gives the optimum experimental parameters for a grey-level image conversion.

本文发表在 Opt. Commun. Vol. 70, No. 3, p.181, 1989

### 用光电系统实现偏振编码的局部细胞逻辑

#### Optoelectronic Implementation of Local Cellular Logic with Polarization Coding

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(中国科学院上海光学精密机械研究所)

本文提出了一个用光电系统来实现局部细胞逻辑的方法。采用偏振编码技术和电子学相减及取阈值技术来实现具有正负互连的操作。给出了边缘增强的拉普拉斯算子的数值模拟结果和实现结果。

An optoelectronic architecture is suggested to perform local cellular logic. A polarization coding technique along with the electronic subtraction and thresholding techniques are developed to complete the operations with both positive and negative interconnections. Experimental results of the Laplacian operator for edge enhancement and their numerical simulations are given.

本文发表在 Micro. & Opt. Tech. Lett., Vol. 3, No. 7, p.242, 1990

### 采用正交投影和成像系统实现并行多矩阵乘法

#### Parallel Multiple Matrix Multiplication Using an Orthogonal Shadow-Casting and Imaging System

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(中国科学院上海光学精密机械研究所)

本文提出了采用正交投影和成像系统实现并行多矩阵乘法。讨论了矩阵乘法器的构成, 给出了用该系统实现多矩阵乘法的初步实验结果。

A novel orthogonal shadow-casting and imaging system is proposed for performing multiple matrix multiplication. An analysis is given for describing the construction of a matrix processor. Preliminary experiments of matrix multiplication are demonstrated.

本文发表在 Opt. Lett., Vol. 15, No. 19, p.1005, 1990

### 光学多通投影相关矩阵—矢量乘法器

#### Optical Matrix-Vector Multiplication Using Multichannel

#### Shadow-Casting Correlator

黄洪欣 刘立人

(中国科学院上海光学精密机械研究所)

基于几何光学的投影相关原理, 本文提出了用非相干多通投影相关器作矩阵—矢量乘法运算的新方法; 讨论了这种矩阵矢量乘法器的一般结构形式和物理极限; 并给出了实验结果。实验表明该方法简单易行。

Based on the shadow-casting correlation of geometrical optics, a new correlation scheme for performing matrix-vector multiplication is proposed. The configuration can be simply regarded as an incoherent multichannel shadow-casting correlator. It is interesting that it is capable of fully parallel input and output, and its structure can be varied according to the demand. The general configuration form and the physical limitation of the scheme proposed here are discussed. Experiments are given, and show that method is very simple.

本文发表在《光学学报》, 第9卷, 第6期, p. 537, 1989

### 利用在 SBN : Ce 晶体中电控光耦合的光致折变空间光调制

#### Photo Refractive Spatial Light Modulation by Electrocontrolled Beam

#### Coupling in SBN: Ce Crystals

马建 刘立人 伍树东 王之江

(中国科学院上海光学精密机械研究所)

基于在 SBN : Ce 的电控双光束耦合效应和耦合增益的像空间调制, 提出了一种新的动态非相干像至相干像转换。通过改变电场可以获得正或负的像复制。

Dynamic incoherent-to-coherent image conversion is proposed, which is based on the effects of electrocontrolled two-beam coupling in SBN: Ce and image spatial modulation

of coupling gain. Either a negative or positive coherent replica is obtained by altering the electric field.

本文发表在 Digest of OSA Topical Meeting on Optical Computing, p. 76, 1989

### 光学复数离散傅里叶变换的相关算法和结构

#### Correlation Algorithm and Architecture for Optical Complex Discrete Fourier Transformation

黄洪欣 刘立人 王之江

(中国科学院上海光学精密机械研究所)

在非相干多通投影相关矩阵——矢量乘法器的基础上, 实现了复数的离散傅里叶变换。讨论了复数的循环矩阵编码方法。实验验证了 DFT 的位移、叠加等性质。

A multichannel incoherent optical correlator for performing complex DFT is proposed. The matrix-code method of complex DFT is discussed, and some properties are demonstrated.

本文发表在 Digest of OSA Topical Meeting on Optical Computing, p.254, 1989

### 用波带片的尺度容限可调谐多通道尺度不变模式识别系统

#### Band-Tunable Multichannel Scale Invariant Pattern Recognition System with Zone Plates

梁敏骅 伍树东 刘立人 王之江

(中国科学院上海光学精密机械研究所)

研究了一种采用波带片的尺度容限可调谐多通道尺度不变的模式识别系统。

A new system of scale invariant pattern recognition, which has a large scale tunable and movable range and utilizes zone plates, is investigated.

本文发表在 Digest of OSA Topical Meeting on Optical Computing, p.322, 1989

### 平行模糊逻辑及光学实现

#### Optical Implementation of Parallel Fuzzy Logic

刘立人

(中国科学院上海光学精密机械研究所)

本文提出了平行模糊逻辑, 并采用面积编码模糊变量和补的多重成像系统及光阈值加以实现。因此用合取或析取范式表示的模糊逻辑函数图像操作能够在一个两级光学系统中完成。对透镜列阵和阈值元件编程, 可以设计所需的模糊逻辑函数, 给出了模拟和实验。

A multiple-imaging scheme with area-coding of input fuzzy variables and negations and thresholding of output intensity is proposed to perform basic fuzzy logic operations in parallel. Thus the pattern fuzzy logic described by a fuzzy logic function in disjunctive and conjunctive normal form can be easily realized in a two-stage optical system. The access of lens-arrays and the thresholding devices. Simulations and experimental results are given, too.

本文发表在 Opt. Commun., Vol. 73, No. 3, p.183, 1989

### 平移, 旋转和尺度不变的光学关联存储

#### Shift-, Rotation-, and Scale-Invariant Optical Associative Memory

林森茂 伍杰 刘立人

(中国科学院上海光学精密机械研究所)

本文详细研究了一种基于新的数字空间变换的光学关联存储系统, 该系统能同时实现平移, 旋转, 尺度和误差不变性。

An optical associative memory based on a new digital spatial invariant transform, which can perform shift-, rotation-, scale-, and error- invariance simultaneously, is described in detail.

本文发表在 SPIE, Vol. 1359, p. 169, 1990

### 采用非相干正交成像系统的光学三矩阵乘法

#### Optical Triple Matrix Multiplication Using Incoherent Orthogonal Image System

黄洪欣 刘立人 王之江

(中国科学院上海光学精密机械研究所)

本文提出了采用非相干正交成像系统并行三矩阵乘法的新方法, 讨论了该方法的原理和实验。

A novel scheme for performing triple matrix multiplication in parallel using incoherent orthogonal image system is proposed. The experiments and physics discussion are given.

本文发表在 SPIE, Vol. 1359, p. 199, 1990

### 光学图形模糊逻辑 Optical Pattern Fuzzy Logic

刘立人

(中国科学院上海光学精密机械研究所)

本文提出了图形模糊逻辑, 采用一个面积编码输入和阈值输出强度的多成像系统来实现上述算法。还提出了一种光栅编码技术来实现上述逻辑。

The pattern fuzzy logic is suggested and performed in a multiple imaging system with area-coding of inputs and thresholding of output intensities. The grating-coding technique is also proposed.

本文发表在 SPIE, Vol. 1359, p.345, 1990

### 实时编码二值仅位相滤波器 Real Time Binary Phase-Only Filter Encoding

梁敏骅 刘立人 王之江

(中国科学院上海光学精密机械研究所)

本文研究了个实时编码二值仅位相滤波器的方案和实现该方案的系统。

A real time binary phase-only filter encoding scheme is described and a system to realize the encoding scheme is designed.

本文发表在 SPIE, Vol. 1359, p.347, 1990

### SBN : Ce 晶体中的电控光耦合和双稳性

## Electrocontrolled Beam Coupling and Bistable Behavior in SBN : Ce Crystals

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(\* 中国科学院上海光学精密机械研究所、\*\* 中国科学院上海硅酸盐研究所)

首次发现了光致折变 SBN : Ce 晶体中电控光耦合新效应: 光耦合的方向和增益可由一外加直流电场控制, 耦合增益和外加电场的关系呈双稳性。利用光致折变的“极化率改变”机制进行了理论解释。

We present the experimental results of electrocontrolled two-beam coupling in photorefractive SBN : Ce crystals. The coupling direction and coupling gain can be predetermined by an externally applied dc electric field, and the coupling gain shows a bistable behavior. A theoretical explanation is also given.

本文发表在 Appl. Phys. Lett., Vol. 53, No. 10, p.826, 1988

## 光致折变 SBN : Ce 晶体中的光束耦合

### Multibeam Coupling in Photorefractive SBN: Ce

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(\* 中国科学院上海光学精密机械研究所、\*\* 中国科学院上海硅酸盐研究所)

首次进行了光致折变晶体中多光束耦合的理论和实验研究。在一个晶体中, 使用一个泵浦光可同时对多个光信号进行光耦合放大。每个信号光的耦合增益是泵浦光与信号光之间耦合的综合结果。信号光的耦合增量依赖于入射信号的强度, 在信号光中存在着耦合竞争效应。

Theoretical and experimental results are presented for simultaneous multibeam coupling in photorefractive SBN : Ce. Within a single crystal, multiple signals are amplified through a coupling process that employs a single pump. The coupling gain of each signal results from coupling both between the pump and the signal and between different signals. The amount of gain that each signal receives is dependent on the intensity of the incident signal; thus a competition for the gain exists among the various signals.

本文发表在 Opt. Lett., Vol. 13, No. 11, p.1020, 1988

## 一种新奇的光学多通道尺度容限可调的傅里叶变换系统: 实验

## Optical Multichannel Scale-Range-Tunable Fourier-Transforming System: Experiment

梁敏骅 刘立人 王之江

(中国科学院上海光学精密机械研究所)

我们演示了一种新奇的光学多通道尺度容限可调的傅里叶变换系统的原理, 实验结果同理论分析结果一致。

We have demonstrated the principle of a novel optical multichannel scale-range-tunable Fourier-transforming system. The experimental results show good agreement with the theoretical analysis.

本文发表在 Opt. Lett., Vol. 15, No. 2, p.93, 1990

## 一种新奇的光学多通道尺度容限可调的傅里叶变换系统: 理论

### A Novel Optical Multichannel Scale-Range-Tunable Fourier Transforming System: Theory

梁敏骅 伍树东 刘立人 王之江

(中国科学院上海光学精密机械研究所)

设计了一种新奇的光学系统, 它具有一个吸引人的特点: 当系统的结构参数选定后, 输入物体的不同尺度的傅里叶谱可以同时获得, 并在同一个平面上彼此重合, 傅里叶变换的尺度容限可以调谐到所需的范围。文中图示了系统结构, 给出了尺度容限和系统参数的数学表达式。计算机模拟结果表明该系统具有良好的性能。

We have design a novel system with an attractive attribute, i. e., with the system's structural parameters deliberately preset, the scale range can be tuned to an expected value while Fourier spectra in different scales with respect to an input object can be obtained simultaneously and coincident on the same plane. The structure of the system is illustrated and the relations between the scale range and the structural parameters of the system are presented. The results of a computer simulation show a good performance of the system.

本文发表在 Opt. Commun., Vol. 70, No. 4, p.299, 1989

## 光电混合处理数学形态学

### Optoelectronic Implementation of Mathematical Morphology

刘立人

(中国科学院上海光学精密机械研究所)

基于光学近域操作和电子非线性反馈, 本文提出了一种光电混合系统来处理形态学像操作: 如膨胀, 收缩, 开放, 关闭和构边。给出了数值模拟及其实验。

An optoelectronic implementation based on optical neighborhood operations and electronic nonlinear feedback is proposed to perform morphological image processing such as erosion, dilation, opening, closing, and edge detection. Results of a numerical simulation are given and experimentally verified.

本文发表在 Opt. Lett., Vol. 14, No. 10, p. 482, 1989

### 基于紧凑编码的三阶互连像平方关联的光电二维神经网络

Optical Implementation of a 2-D Neural Net with a Third-Order

Interconnection for Image Quadratic Associative

Memory Based on a Compact-Encoding Method

林森茂 伍杰 刘立人

(中国科学院上海光学精密机械研究所)

本文报导了一种三阶互连像平方关联存储的两维神经网络光电处理系统, 特别是提出了一种可以大大减少互连张量尺寸的紧凑编码方法。给出了实验结果。

The optical implementations of a 2-D neural net with a third-order interconnection for image quadratic associative memory are reported. Two types of incoherent optical systems, based on multiple imaging and correlation, are used. In particular, a compact-encoding method, which can greatly reduce the size of the interconnection tensor, is also proposed. The experimental results are given.

本文发表在 Micro. & Opt. Tech. Lett., Vol. 2, No. 8, p. 304, 1989

### 构成多矩阵乘法器的原理

Principle for Making Up Optical Multiple Matrix Multiplier

黄洪欣 刘立人

(中国科学院上海光学精密机械研究所)



本文描述了构成全并行多矩阵乘法器的一般方法, 基于高斯光学导出了三矩阵乘法器 (TMM) 的必要条件。讨论了三矩阵乘法器的两种典型的结构。

A general approach for making up fully parallel optical matrix multiplier is described. The necessary conditions of triple matrix multiplier (TMM) are induced based on Gaussian optics. Two typical configurations of TMM is discussed.

本文发表在 SPIE, Vol. 1319, p.188, 1990

### 采用轮廓仅位相滤波的模式识别

#### Pattern Recognition with a Phase-Only Matched Filter

##### Made from Outline Features

梁敏骅 余敏 刘立人 伍树东 王之江

(中国科学院上海光学精密机械研究所)

本文报道了采用轮廓仅位相滤波的模式识别, 比较了该方法和其它方法的分辨本领。结果表明, 本文所报道的方法比 Horner-Gianino 仅位相滤波器具有更好的分辨本领。

Pattern recognition with a phase-only matched filter made from outline features is reported. Computer simulation of discrimination capabilities of this method and other methods are presented. The results show that our filtering method has a better discrimination capability than Horner-Gianino filtering method.

本文发表在 SPIE, Vol. 1230, p.785, 1990

### 自异关联存储的同时实现: Hopfield 模型的改进

#### Simultaneous Realization of Auto-& Hetero-AM:

##### a Modification of Hopfield Model

周涵纓 刘立人 王之江

(中国科学院上海光学精密机械研究所)

如人脑一样运作的自异关联存储的同时实现是令人感兴趣的。本文提出了一个 Hopfield 神经网络模型的改进模型。这个新模型只需增加很少的记忆就可同时实现自异关联存储, 给出了计算机模拟结果, 分析了信噪比。

It is interesting to realize auto-& hetero-AM simultaneously as human brain acts. In

this paper, a modification of basic Hopfield neural network model is proposed. This model can function simultaneously both as two classes of associative memory with less increase in memory. The result of computer simulation and analysis of the SNR is given.

本文发表在 SPIE, Vol. 1230, p. 753, 1990

### 非相干光实现的二维复数离散傅里叶变换系统 Incoherent Optical Implementation of 2-D Complex Discrete Fourier Transform

张 莉 刘立人

(中国科学院上海光学精密机械研究所)

本文给出了用相干光束来实现复数离散傅里叶变换的方法, 建立了一个多成像光学系统。此系统充分利用了光的平行处理特性, 二维数据可同时处理。光学上的复数表示可采用两种编码方法来实现。我们选取了  $N=6$  二维数据来验证上述方法, 实验所获得的结果与计算机模拟相一致。

A method is given in this paper using incoherent light to realize 2-D complex discrete Fourier transform (DFT). A multi-imaging system is set up, which fully uses the inherent property of optical parallel processing, and 2-D input data can be processed simultaneously. A complex can be optically expressed by two encoding methods. 2-D input data of  $N=6$  is chosen to verify the method. The experimental results accord well with the simulant results of computer.

本文发表于《光学学报》, 第9卷, 第11期, 第1013页, 1989年

### 三阶互连平方关联的光电混合神经网络 Opto-Electronic Implementation of a Neural Network with a Third- Order Interconnection for Quadratic Associative Memory

林森茂 刘立人

(中国科学院上海光学精密机械研究所)

本文给出了三阶互连平方关联存储的光电混合处理神经网络实现方法。采用了多重成像和相关系统。三维互连用二维矢量矩阵安排实现。两值互连也用偏振编码解决。给出了实验结果。

The opto-electronic implementations of a neural network with a third-order interconnection for quadratic associative memory are reported in this paper. Two types of incoherent optical systems based on multiple-imaging and correlation are used where a 3-D interconnection is realized with 2-D mask of a vector matrix arrangement. A coding method of the bipolar interconnection by using a single bipolarized mask is also proposed. The experimental results are given.

本文发表在 Opt. Commun., Vol. 73, No. 4, p.268, 1989

## 基于光致折变晶体中双光束耦合的选择性擦除机制的实时可控空间滤波器 Controllable Real-Time Simple Spatial Filter Based on Selectively Erasing in Photorefractive Two-Beam Coupling

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在 SBN:Ce 光致折变晶体的双光束耦合中, 像的傅里叶谱的位相光栅可以由另外一束光来进行选择性的擦除, 基于这一机制, 我们提出了一种新的动态空间滤波器, 它具有操作可控和结构简单的优点。给出了高通滤波器的计算机模拟和光学实验的研究结果。

Based on selectively erasing part of phase gratings of an image Fourier spectrum by an extra beam in photorefractive two-beam coupling in a SBN: Ce crystal, a new dynamic simple spatial filter is proposed which has the advantages of both controllable operation and simple experimental arrangement. Computational simulation and experimental demonstration are made with an example of high passing filtering.

本文发表在 Opt. Commun., Vol. 74, No.1,2, p.15, 1989

## 从轮廓特征中提取的仅位相滤波器相关 Correlation with a Phase-Only Matched Filter Made from Outline Feature

梁敏骅 余 敏 刘立人 伍树东 王之江

(中国科学院上海光学精密机械研究所)

提出了一种可用光学方法实现的新方法, 该方法可以获得高的相关峰强度和高的光效

率。计算机模拟结果表明, 该方法具有更好的相关输出, 比仅位相滤波器具有更好的敏感性。

To obtain a high correlation peak intensity, a high optical efficiency, and high rotation and scale sensitivities, a new method, which can be realized optically, is proposed. Computer simulation results show that this method will have a neater output and better sensitivities than phase-only matched filter.

本文发表在 Micro. & Opt. Tech. Lett., Vol. 2, No. 3, p.94, 1989

### 轮廓特征中提取的仅位相滤波器的分辨本领

#### Discrimination Capability of a Phase-Only Matched Filter Made from Outline Features

梁敏骅 刘立人 伍树东 王之江

(中国科学院上海光学精密机械研究所)

本文研究了从轮廓特征中提取的仅位相滤波器的分辨本领, 计算机模拟结果表明, 第一类从轮廓特征中提取的仅位相滤波器的分辨本领要优于 Horner-Gianino 滤波器。

The discrimination capability of a phase-only matched filter made from outline features is investigated. Computer simulation results show that the discrimination capability of the first kind of a phase-only matched filter made from outline features is better than a Horner-Gianino filter.

本文发表在 Opt. Commun., Vol. 75, No. 3,4, p. 231, 1990

### 二维关联存储的两维 Hopfield 模型的光学实现

#### Optical Implementation of the 2-D Hopfield Model for a 2-D Associative Memory

林森茂 刘立人 王之江

(中国科学院上海光学精密机械研究所)

本文提出了用多重成像和相关操作的两种非相干光学系统实现基于两维 Hopfield 模型的两值像关联存储, 也提出了一种异关联存储的修正 Hopfield 模型。因此同一系统能实现两种关联存储。给出了实验。

Two kinds of incoherent optical systems based on multiple-imaging and correlation are suggested to implement the 2-D Hopfield model for a binary image associative memory. Then a modified 2-D Hopfield model for a hetero-associative memory is introduced. Therefore, auto- and hetero-associative memories can be implemented in the same systems. Experiments are given, too.

本文发表在 Opt. Commun., Vol. 70, No. 2, p.87, 1989

### 光逻辑运算与莫尔条纹

#### Optical Logical Operation and Moire Patteen

张家军 刘立人

(中国科学院上海光学精密机械研究所)

基于光逻辑运算, 提出了一种产生莫尔条纹拍的新方法。首先将光栅周期性地编码, 然后用 4f 系统解调编码光栅。实验验证了该方法的原理。

Based on optical logical operations, a new approach to extract a specific beat pattern from superposed periodic structures is proposed. Gratings are first periodically encoded and then processed by logical operation. Experimental results are presented.

本文发表在 Opt. Commun., Vol. 66, No. 4, p.179, 1988

### 多通道光学相关器实现快速并行复数离散傅里叶变换

#### Fast Parallel Complex Discrete Fourier Transforms Using a Multichannel Optical Correlator

黄洪欣 刘立人 殷耀祖 赵丽英

(中国科学院上海光学精密机械研究所)

基于多通道非相干光相关器, 本文提出了执行复数离散傅里叶变换的新方法。复数用三个非负实数表示, 而每个实数用矩阵孔径的面积编码。实验验证了 DFT 的位相和叠加性。

Based on a multichannel incoherent optical correlator, a new simple scheme is proposed for performing a complex discret Fourier transform. A complex value is represented by using three nonncgative reals, and every real is encoded with the area of a rectangular aperture. A  $3N \times 3N$ -element kernel mask together with a  $3N$ -element 1D-pin-hole-ar-

ray illuminated with an extended source is used to calculate an 1D-DFT of an N-point input. Some properties of DFT are demonstrated in experiments.

本文发表在 Opt. Commun., Vol. 68, No. 6, p.408, 1988

## **GaAs-GaAlAs 异质结脊型波导阶跃 $\Delta\beta$ 定向耦合器** **GaAs-GaAlAs Heterostructure Rib Waveguide stepped $\Delta\beta$ Directional Coupler**

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具有肖特基势垒电极的 GaAs-GaAlAs 异质结脊型波导阶跃  $\Delta\beta$  定向耦合器已经被研究。在研制过程中通过合理设计器件结构,降低载流子浓度以及采用反应离子蚀刻和剥离等技术,使器件总损耗降为 10dB,消光比 26.8dB,器件在 1.3 $\mu\text{m}$  下实现单模工作。

GaAs-GaAlAs heterostructure rib waveguide directional coupler with “stepped  $\Delta\beta$ ” Schottky electrodes has been investigated by using ion-etching and liftoff mask techniques, and optimization design of device structure and lowering epitaxy laser carrier concentration in investigated and fabrication process. Total losses were 10dB. An extinction ratio of 26.8dB was obtained, for single-mode optical systems operating at 1.3 $\mu\text{m}$ .

本文发表在《第六届全国化合物半导体和微波光电子器件学术会议论文集》

## **GaAs-GaAlAs 异质结波导 Mach-Zehnder 干涉调制器** **GaAs-GaAlAs Heterostructure Rib Waveguide Mach-Zehnder Interferometric Modulator**

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具有 Y-分支的 GaAs-GaAlAs 异质结脊形波导 Mach-Zehnder 干涉调制器已经被研究。在研制过程中采用了 Au 肖特基势垒电极,反应离子蚀刻和剥离等技术,器件总损耗为 10dB,消光比为 26.6dB,半波电压 17.6V,器件在 1.3 $\mu\text{m}$  下实现了单模工作。本文在简述其工作原理的同时介绍了器件设计、研制工艺和特性分析。

GaAs-GaAlAs heterostructure electro-optic rib waveguide Mach-Zehnder interferometric modulator with Y-branches has been investigated, by using ion-etching

and liftoff mask techniques. The device total losses was 10dB, An extinction ratio of 26:6dB, and the half wave voltage of  $V\pi = 17.6\text{V}$  was obtained, for single-mode optical systems operating at  $1.3\mu\text{m}$ . We introduce the device principle, device design, fabrication, and character.

本文发表在《第五届全国凝聚态光学性质学术会议论文集》

## 二维 Mellin 变换的实现

### Realization of Two-dimensional Mellin Transform

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本文分析了 Mellin 变换的光学实现问题, 提出一种实现 Mellin 变换的新方法, 并对此进行了实验研究和给出了实验结果。

In this paper, we analyze optical realization of the 2-D Mellin transform, and propose a new method to perform the transform. The 2-D Mellin transform experiment is carried out, and the experimental results are given.

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## 用全息掩膜实现二维线性变换

### Performing a 2-Dimensional Linear Transform with a Holographic Mask

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基于由全息掩膜和傅氏变换透镜组成的相干光学系统, 提出了进行二维线性变换的一种方法。对二维 32 序的沃尔什-哈特曼变换进行了光学实验, 并给出了满意的实验结果。

Based on the configuration of coherent optical system composed of a holographic mask and two Fourier transform lenses, an approach of performing a 2-dimensional (2-D) linear transform is suggested. The 2-D Walsh-Hadamard transform of order 32 is optically tested, and the experimental results that are satisfactory are given.

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## 用于计算叠加积分的光电混合系统

### A Hybrid Optical-Digital System for Computing Superposition Integral

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(中国科学院物理研究所)

本文叙述了一个用于计算叠加积分的光电混合系统, 它由全息掩膜、透镜、CCD 与微机组成。此系统在原则上可以用于实现任意给定的线性变换、矩阵相乘运算和提取图形的特征。此系统的光学部分是  $4f$  系统, 通过光波在此系统中的传播和掩膜的调制作用实现其积分核的功能。掩膜用计算机产生全息图的方法研制。在实验上, 用此系统进行了沃尔什-哈特曼变换, 矩阵相乘运算和几何矩积分。实验结果表明, 上述这些积分的测量值同理论值符合。

In this paper, a hybrid optical-digital system, consisting of a holographic mask, two Fourier lenses, a CCD detector and a microcomputer, is presented for computing a superposition integral, which is expressed as the integral of input data and impulse response or point-spread-function. In principle, the system can be used for performing an arbitrary linear transform and multiplication of matrices, as well as extracting the features of a pattern. In this system all the spacings between the input, lens, mask and output planes are equal to the focal length of Fourier lens. The point-spread function is represented by the progress of lightwave propagating through the optical system and modulating in the mask. The mask is produced by using computer-generated-hologram techniques. In experimental research, the system is tested by Walsh-Hadamard transform, matrix multiplication and geometric moment integral. The experimental results show that, the measured values of the above integrals are in agreement with the theoretical calculations.

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## 用于提取图像不变矩的光电混合系统

### A Hybrid Optical-Digital System for Extracting Invariant Moments of Images

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(中国科学院物理研究所)

本文基于光学普遍变换理论, 提出了一种用于提取图像不变矩的光电混合系统, 此系统由单个全息透镜组成。我们用两组图像作为输入显示该系统的图像分类功能。实验结果表明, 由该系统得到的不变矩的确展示了不变矩的平移与比例不变特性。



A hybrid optical-digital system for extracting invariant moments of images. In this report, we present a new hybrid optical-digital system composing of a single holographic mask for extracting the invariant moments of an image based on the theory of optical general transform. We use two groups of images as input to demonstrate the function of image classification of our system. The experimental results show that invariant moments extracted from this system indeed exhibit translation and scaling invariances.

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### 高序光学变换

#### Study on Optical Transformation in High Sequence

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从低序光学变换到高序光学变换在实验上存在着困难, 本文分析研究了这些困难问题, 并提出用 5 平面光学系统能够较为理想地解决这些问题, 并以一维 32 序的 Walsh 变换为例, 在实验上建立了 3 平面和 5 平面两个光学系统。对此进行的实验研究, 实验结果与理论预期一致。

There is some trouble in experimental study of optical transformation developing from low-to high-sequence. In this paper, to solve these problems, a three-plane and a five-plane experimental systems have been established to realize the 1-dimensional 32-sequence Walsh transformation. The experimental results are in agreement with theoretical expectations.

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### 32 和 64 序的光学沃尔什-哈特曼变换

#### Optical Walsh-Hadamard Transform for Orders 32 and 64

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提出和描述了由一个全息掩膜和二傅氏变换透镜组成的相干光学系统, 用该系统可以实现任意的线性变换, 并给出了决定掩膜复振幅分布的一组方程组。作为一种具体的变换, 在光学上实现了 32 和 64 序的沃尔什-哈特曼变换。

A optical system composed of a holographic mask and two Fourier lenses is described for performing an arbitrary linear transform. A set of equations for determining the amplitude-phase distribution of the mask is given. As a specific transform, the Walsh-Hadamard transform for orders 32 and 64 is optically made in 1-D space.

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## 二维光学沃尔什-哈特曼变换

### 2-Dimensional Optical Walsh-Hadamard Transform

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从光学变换的基本方程出发, 分析了变换所需的空域横向调制型全息透镜的相位误差, 提出用计算机产生全息图和光学全息相结合的方法产生高精度的二维变换全息透镜。在实验上实现了二维 32 序的光学沃尔什-哈特曼变换, 实验结果与理论计算一致。

Based on the equations of the optical transform, phase errors of the holographic lens used in a transform caused by space-transverse-modulation is analysed, and a method of computer generated hologram combined with optical holography is proposed to generate a 2-dimensional (2-D) holographic lens suitable for 2-D transform. The 2-D Walsh-Hadamard transform in 32-sequence is optically realized. The experimental results are in agreement with the theoretical calculations.

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## GaAs / GaAlAs 单量子阱电光吸收和光调制

### Electroabsorption and Light modulation in GaAs / GaAlAs

#### Single Quantum Well Structure

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制作并研究了 GaAs / GaAlAs 分别限制单量子阱台面条形单模波导电致吸收光调制器。量子阱宽度为 10nm, 长度为 700 $\mu$ m 的器件, 当传输光波长为 865nm 时 TE 偏振最大调制深度 (开关比) 为 29.7dB, 插入损耗吸收分量为 3dB; TM 偏振最大调制深度为 28.5dB。用 2V 电压幅度可以得到 15dB 的开关比。光电导谱的测量表明, 偏压从 +0.5V 变到 -7V 时吸收边的红移为 60nm, 即量子阱中室温激子的共振吸收峰移动了 96MeV。

单阱高场条件下首次观察到了导带第二能级电子和价带第一能级空穴激子的共振吸收线的出现、增强和移动。

GaAs / GaAlAs graded-index separate confinement single quantum well heterostructure single mode ridge waveguide electroabsorption modulator was fabricated and investigated. For the modulator with the quantum well width 10nm and the device length 700 $\mu$ m an on / off ratio of 29.7dB and absorption insertion loss of 3dB were obtained for TE polarized light with wavelength 865nm, and for TM polarization the on / off ratio was 28.5dB. With 1V amplitude of the switching voltage an on / off ratio of 15dB was achieved. Photocurrent spectra exhibited a red shift of 60nm of the absorption edge when the voltage applied to the PIN diode was varied from +0.5V to -7V. The corresponding shift of the room temperature exciton peak energy was 96MeV.

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### InP 和 InGaAsP 晶体上衍射光栅的刻制技术

#### Technique for Fabricating Diffraction Gratings on InP and InGaAsP Crystals

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采用全息光刻技术, 在 InP 和 InGaAsP 晶体上刻制亚微米衍射光栅, 获得较好的重复性和均匀性, 并已应用于研制长波长分布反馈激光器。

This paper describes the technique of fabricating gratings that involves wet chemical etching through a photoresist mask that has been patterned by laser interference exposure. Both first- and second-order gratings in InP and InGaAsP for 1.55 $\mu$ m distributed feedback lasers with high uniformity and reproducibility have been fabricated.

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### 低阈值 InP / InGaAsP PBH 双区共腔双稳激光器

#### InP / InGaAsP PBH Common-Cavity Two-Sections

## Bistable Lasers with Low Threshold Current

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一种平面掩埋异质结构 (PBH) InP / InGaAsP 双区共腔双稳激光器已研制成功。器件具有良好的光学双稳特性。激射波长  $1.3\mu\text{m}$ 。直流  $L/I$  特性显示典型的回滞曲线。导通阈电流  $I_{\text{thon}} > 40\text{mA}$ , 最低者  $26\text{mA}$ , 低于文献报导的最好值。在通态电流跨度内, 器件以单纵模激射。数字光放大增益  $G > 25\text{dB}$ , 最大者超过  $30\text{dB}$ 。导通时间  $\tau_{\text{on}} < 300\text{ps}$ , 关断时间  $< 1\text{ns}$ 。

InP / InGaAsP PBH Common-Cavity Two-Sections (CCTS) bistable lasers emitting at  $1.3\mu\text{m}$  have been developed by two step LPE. The devices behave good optical bistabilities. The typical bysteresis exhibiting in  $L/I$  curve has been obtained. The turn-on threshold current  $I_{\text{thon}} > 40\text{mA}$ , the lowest value as low as  $26\text{mA}$  has been achived which is lower than the best Value in literature. The single longitudinal mode operation in the current span of the turn-on state has been realized. The optical figure amplification gain factor  $G > 25\text{dB}$ , the largest value is more than  $30\text{dB}$ . The turn-on time  $\tau_{\text{on}} < 300\text{ps}$  and turn-off time  $\tau_{\text{off}} < 1\text{ns}$ .

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## ZnS-ZnSe 应变层超晶格远红外反射谱研究

The Study of Far-Infrared Reflectivity Spectra of ZnS-ZnSe  
Strained-Layer  
Superlattices

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远红外反射谱是研究超晶格横光学声子模特性的有效方法, 也是检测其结构性质的简单方法。我们首次测量了 II-VI 族宽禁带 ZnS-ZnSe 应变层超晶格的远红外反射谱, 用计算机进行曲线拟合到一些基本的材料参数, 并分析了横光学声子模频率移动与结构参数的关系。

Far-infrared reflectivity measurement is a simple way to study the TO phonon modes of SLS as well as to characterize the quality of the microstructures. We, for the first time, have obtained the far-infrared reflectivity spectrum of II-VI wide gap ZnS-ZnSe

strained layer superlattice. Fitting the measured curve with computer, we have determined some phonon parameters. On the mean time, we have studied the frequency shifts of the TO phonon modes.

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### **ZnSe-ZnS 多量子阱光学双稳态器件**

#### **ZnSe-ZnS Multiple Quantum Well Optical Bistable Device**

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以 YAG 三倍频光为激发光源, 我们首次在室温下观测到用分子束外延生长的 ZnSe-ZnS 多量子阱标准具的脉冲压缩效应。根据入射脉冲和透射脉冲波形, 得到了该器件的双稳回线。器件的开关功率约为  $0.1\text{W}/\mu\text{m}^2$ , 开关时间约为 10ns。

The Characteristics of a Fabry-Perot cavity type ZnSe-ZnS multiple quantum well (MQW) optical bistable device (OBD) were measured by using the third harmonic beam of a YAG laser as the exciting source. The MQWs were grown by molecular beam epitaxy. We have, for the first time, observed the apparent pulse compression effect for the OBD and obtained the hysteresis loop according to the relation between the incident pulse power and the transmitted power. The intensities required for bistable operation are about  $0.1\text{W}/\mu\text{m}^2$  and the switching times are about 10ns.

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### **ZnSe-ZnTe 应变层超晶格的原子层外延生长**

#### **Atomic Layer Epitaxy of ZnSe-ZnTe**

##### **Strained-Layer Superlattices**

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我们首次采用国产 III 型分子束外延设备在 InP 衬底上用原子层外延法成功地生长了 ZnSe-ZnTe 应变层超晶格。材料的晶体质量用反射高能电子衍射进行实时监测。从低高

度 X 射线衍射曲线可以算出超晶格的周期, 结果与计算原子层数所得之值吻合得很好。

ZnSe-ZnTe strained-layer superlattices were grown by atomic layer epitaxy. The crystal quality was examined by in situ reflection high energy electron diffraction. Low angle X-ray diffraction was measured. The period of the SLSs calculated from the diffraction peaks agrees with that calculated from the on-off run numbers of the shutters.

本文发表在“1989 砷化镓及有关化合物会议”, 安徽, 黄山, 1989 年

### ZnSe-ZnS 及 ZnSe-ZnTe 超晶格的 MBE 生长及特性

#### MBE Growth and Characterization of ZnSe-Zns

#### and ZnTe-ZnSe Superlattices

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采用分子束外延方法生长了 ZnSe-ZnS 及 ZnSe-ZnTe 等超晶格材料。从 RHEED 图像观察到了明显的菊池线, 表明该超晶格材料具有平整的表面结构和很好的晶体质量。超晶格截面的 AES 分析, 透射电镜的 TED 图上卫星点都表明超晶格界面质量很好。以 Ar 离子激光作激发光源测试了 50 (ZnSe-ZnTe) (4nm-4nm) 超晶格的 PL 光谱, FWHM 约为 62.3MeV。

(ZnSe-ZnS) / GaAs(Sub.), (ZnSe-ZnTe) / InP(sub.),  
(ZnSe-ZnSe<sub>1-x</sub>Tex) / GaAs(sub.), (ZnSe-ZnS) / ZnS / GaAs(sub.)superlattices were grown by molecular beam epitaxy. The clear Kikuchi lines observed in RHEED patterns show that the superlattices are of flat surface and good crystalline quality. The AES analysis and satellite points observed in TED show excellent interface quality. PL spectra are measured for 50(ZnSe-ZnTe)(4nm-4nm)SLS. The FWHM is about 62.3MeV.

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### 宽禁带 II-VI 族半导体超晶格折射率测量及吸收研究

#### Determination of Refractive Index and Study of

#### Absorption in Wide Gap II-IV Semiconductor

#### Superlattices

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我们在室温下用双束反射测量了 ZnSe-ZnTe 及 ZnSe-ZnS 应变层超晶格的折射率。折射率曲线在能量等于基态电子空穴跃迁能处出现不连续。超晶格的折射率与块状材料的折射率差别较大。我们还采用有效阱宽模型在有效质量近似下计算了 ZnSe-ZnS 多量子阱在外加电场下激子峰的移动。

The refractive indices of ZnSe-ZnTe and ZnSe-ZnS strained-layer superlattices (SLSs) were determined by double-beam reflectance measurements at 300K. A discontinuity was found in the index spectra at about the energy equal to the transition energy  $E_1(e-h)$  between  $n=1$  confined electron and hole levels. Large difference was found between the indices of the SLSs and those of the compositional bulk materials. Using the effective infinite-well model within effective mass approximation and taking into account the large strain effect, we also calculated the shifts of the exciton peaks with applied electric fields for ZnSe-ZnS multiple quantum wells (MQW).

本文发表在“6th International Conference on MBE”, San Diego, USA, Aug.28-31, 1990

### 波导型 ZnSe-ZnS 超晶格光双稳器件的制作

#### The Fabrication of Rib Waveguide Type ZnSe-ZnS SLS Optical Bistable Device

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作者在研制成 F-P 腔透射式多量子阱光学双稳器件的基础上, 又研制成了端面耦合 ZnSe-ZnS 超晶格脊形波导结构。所用超晶格片子是利用分子束外延 (MBE) 技术, 由 ZnSe, ZnS 交替生长 100 周期形成, 整个厚度为  $1.5 \sim 2\mu\text{m}$ 。波导结构由  $\text{SiO}_2$  作掩膜, 再进行光刻腐蚀而成, 其宽为  $10\mu\text{m}$ , 长约  $500\mu\text{m}$  左右。作者以 He-Ne 激光 ( $632.8\text{nm}$ ) 作光源, 成功地对 ZnSe-ZnS 脊形波导进行了导波试验。

The II-VI wide gap semiconductor superlattices such as ZnSe-ZnS are potential materials for opto-electronic applications in the visible region. After the obtaining of the Fabry-perot etalon type MQW optical bistable devices, we have fabricated the ZnSe-ZnS strained-layer superlattice end-fire rib waveguide for convenient integrated of the BOD with other opto-electronic device The 100 periods ZnSe-ZnS superlattice is grown by MBE, the whole thickness is about  $1.5 \sim 2\mu\text{m}$ , The rib waveguide with  $10\mu\text{m}$  wide and about  $500\mu\text{m}$  long is fabricated by etching technigue using  $\text{SiO}_2$  as mask. The light transmission experiments are successful.

本文发表在《第四届全国纤维光学与集成光学学术交流会》，长春，1990年

### **ZnSe-ZnTe 应变层超晶格远红外反射谱**

#### **Far-Infrared Reflectivity Spectra of ZnSe-ZnTe Strained-Layer Superlattices**

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本文首次报道室温下测量的分子束外延生长的 ZnSe-ZnTe 应变层超晶格的远红外反射谱。得到了 ZnSe、ZnTe 横光学声子模。用长波长超晶格介电理论和多层吸收薄膜理论进行曲线拟合，确定 II-VI 族 ZnSe、ZnTe 材料的一些基本材料参数，如横光学声子频率、模衰减常数、模振荡强度、高频介电常数等。本文首次报道这些参数。

Far-infrared reflectivity spectra have been measured for the first time on ZnSe-ZnTe strained-layer superlattices grown by molecular beam epitaxy. The spectra at 300K display the ZnSe and ZnTe transverse optical phonon modes. The reflectivity spectrum can be explained by the long wavelength superlattice dielectric theory and the reflection theory of multiple absorbing layers. Fitting the experimental data with the computer calculated curve, the transverse optical phonon frequencies, mode damping constants, mode oscillator strengths and high frequency dielectric constant have been determined.

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### **波导型及 F-P 腔型 ZnSe / ZnS、ZnSe / ZnTe 量子阱 BOD 结构**

#### **ZnSe / ZnS ZnSe / ZnTe Quantum Well Bistable Optical Devices (BOD) Structures**

with Waveguide and Fabry-Perot Resonator

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本文报导了用分子束外延 (MBE) 方法，在 GaAs 和 InP 衬底上成功地生长 ZnTe-ZnSe 和 ZnSe-ZnS 两种超晶格材料，在此基础上，我们已制作了超晶格波导型和 F-P 腔型光学双稳态器件结构。



In this paper, we reported that ZnTe-ZnSe / InP, ZnSe-ZnS / GaAs superlattices have been grown by MBE. The bistable optical devices with F-P etalon and waveguide structures were fabricated by using these superlattices materials.

本文发表在《1989 光电子器件与集成技术年会》，北京，清华大学

## II-VI / III-V 应力层超晶格材料与器件

### II-VI / III-V Strained-Layer Superlattice Materials and Devices

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本文研究了 II-VI 族宽带半导体超晶格的光学特性。首次观察到了 ZnSe-ZnS 多量子阱的脉冲压缩效应、ZnSe-ZnS 超晶格中的折叠 LA 声子模及 ZnSe-ZnTe 超晶格中的限制 LO 声子模。通过 Raman 散射首次确定了 ZnSe-ZnTe 超晶格的临界厚度。

The optical properties of II-VI wide gap semiconductor SLSs were studied. We report, for the first time, the pulse compression in ZnSe-ZnS MQW, the fold LA phonon modes in ZnSe-ZnS SLS and the confined LO phonon modes in ZnSe-ZnS SLS. The critical thickness of ZnSe-ZnTe were determined by Raman scattering.

本文发表在“MRS 1990 Fall Meeting”, Boston, USA, Nov.26- Dec.1, 1990

## ZnSe-ZnTe 和 ZnS-ZnSe 应变层超晶格声子模与晶格应变的光谱研究

### The Study of Phonons and Lattice Strains in ZnSe-ZnTe and ZnS-ZnSe Strained-Layer Superlattices by Raman and Far-Infrared Reflectivity Spectra

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我们首次在室温下用非共振 Raman 背散射方法测得 ZnSe-ZnTe 应变层超晶格限制在 ZnSe 层中的全部纵光学声子模，同时测得 ZnS-ZnSe 应变层超晶格的纵声学声子折叠模。得到 LO 模频移与结构参数的关系，初步确定具有 7% 晶格失配的 ZnSe-ZnTe 应变层超晶格的临界厚度为 4nm。计算了超晶格限制效应引起的 LO 声子模的红移和弹性应变引起的移动，表明后者是引起声子模频移的主要原因。ZnSe 层所受伸张应力使 LO 模产生的红移和 ZnTe 层所受压缩应力引起的 LO 模的蓝移使各层的 LO 声子限制模发生重叠，从而诱导出 LO 声子折叠模，这也在 Raman 背散射中观测到。我们还用远红外反射

谱研究了这两种超晶格的 TO 声子模特性。

We have observed, for the first time, the confined LO phonon modes in ZnSe layer of the ZnSe-ZnTe strained layer superlattice (SLS) and the folded LA phonon modes in ZnS-ZnSe SLS by off-resonance Raman scattering at room temperature. The relation between LO mode shifts and the superlattice structure parameters had been determined for ZnSe-ZnTe SLS. We have calculated the red shifts of LO phonon frequencies due to confinement and the shifts induced by the elastic strains, which are much larger than the red shifts due to confinement. The red shifts induced by tensile strain in ZnSe layer and the blue shifts induced by compressive strain in ZnTe layer made the confined LO modes in two individual layers overlap. Therefore, the folded LO mode had been observed in ZnSe-ZnTe SLS. We have also studied the transverse optical phonon modes in the two SLS systems by means of far-infrared reflectivity spectra. ZnSe layers are under different stress in the two SLS systems.

本文发表在“MBE-6 International Conference”, Aug. 27-31, San Diego, USA, 1990 年

### 共腔双稳态半导体激光器的实验研究

#### Experimental Results for a CCTS Bistable DH Laser

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本文对  $\text{SiO}_2$  掩蔽隔离的脊形波导条形结构 InGaAsP / InP DH 双稳态激光器进行了研究, 这种器件具有内部 Q 开关特性。对其稳态 L-1 特性, 阈值电流与温度的关系, 激射光谱与温度的关系及在激射情况下的光谱特性进行了测量, 得到了初步的结果。

Experimental results are presented regarding a Ridge-Waveguide stripe structure bistable InGaAsP / InP laser formed by a  $\text{SiO}_2$  cover. There is a Q-switched modulation due to saturable absorber in it. The characteristics of L-1 spectra and threshold currents relative to the temperature and spectra exciting state are measured.

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### P 型衬底掩埋新月条形 InGaAsP 激光器的高频响应

#### High-Frequency Response of P-Substrate Buried Crescent InGaAsP Lasers

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本文报导了 P 型衬底层新月条形激光器 (PBC) 在矩形电脉冲激励下的室温张弛振荡特性的实验结果。其振荡频率与输出光功率有关。对于腔长为  $350\mu\text{m}$  的器件, 在注入电流为阈值电流的 3.8 倍, 单面输出光功率为 9mW 时, 最高张弛振荡频率为 12.1GHz; 等效于 3dB 截止频率为 18.8GHz。这是目前 PBC 结构条形激光器公开报导的最高张弛振荡频率。

The relaxation oscillation frequency of p-substrate buried crescent InGaAsP lasers is measured as a function of the output power in the switched-on state. The lasers are excited by a steplike current pulse at room temperature. The highest resonance frequency observed for a  $350\mu\text{m}$  long cavity is 12.1 GHz equivalent to an intrinsic 3-dB cutoff frequency of 18.8GHz at an optical power of 9mW / facet according to an injection current of 3.8 times threshold current, this is so far the best ever published value for a p-substrate laser.

本文发表在 J. Appl. Phys, 68(5), 1 September 1990

### 双稳激光器的瞬态响应和光放大特性

#### The Transient Response and Optical Amplification in a Bistable Double Heterojunction (DH) Laser

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我们采用单模速率方程计算和分析了双区共腔双稳激光器在横向和轴向两种不同的光注入方向下的瞬态响应和光放大特性。结果表明轴向光注入比横向光注入具有更高的开关灵敏度和光放大系数。

In this paper, using the single longitudinal mode rate equations in which the external light injection was considered, we analysed the properties of the transient response and the optical amplification under two different light injection conditions: i.e., Axial injection and crosswise injection. It shows that, the axial injection has higher sensitivity of switching and larger light amplification coefficient to amplify the optical signal.

本文发表在“10th IEEE International Semiconductor Laser Conference”, 1986

## 双区共腔双稳激光器(CCTS)的动态特性

### The Dynamic Characteristics

#### in a Common Cavity with Two Sections Bistable Laser

王启明 刘文旭 赵建和 吴荣汉

(中国科学院半导体研究所)

本文给出了双区共腔双稳激光器 (CCTS) 的张弛振荡、自脉动和混沌等动态特性的一些实验结果。基于器件的强 Q 开关效应, 用一短脉宽的电脉冲 ( $\approx ns$ ) 很容易获得一个 FWHM 小于 10ps 的高速光脉冲。为了简化速率方程的计算和改善器件的性能, 我们首次应用相关注入来分析双区共腔双稳激光器 (CCTS) 在两端和三端工作状态下的动态特性。

In this paper, experimental results are given of dynamic characteristics in a CCTS laser with relaxation oscillation, self-sustained pulsation and chaos being included. Based on the strong Q-switch effect of device, an ultrafast light pulse with FWHM less than 10ps has been easily attained by applying a short duration electric pulse ( $\approx ns$ ). To simplify the calculation of mode rate equations and to develop the functions of the device, a correlation injection is used for the first time to analyse the dynamic behaviour of the CCTS laser under 2 terminal and 3 terminal operation.

本文发表在“11th IEEE International Semiconductor Laser Conf”, 1988

## 半导体双稳态激光器在光注入下的实验研究

### Experimental Results for a CCTS Bistable DH Laser under Optical Injection

王启明 吴荣汉 李建蒙 吴洪

(中国科学院半导体研究所)

本文报道了 InGaAsP / InP 双区共腔脊形波导双稳激光器在外光注入下产生光-光双稳特性及光-光放大的实验结果, 给出了器件在直流及脉冲工作时的光-光双稳特性, 并对结果进行了初步分析。

Experimental results are reported for a CCTS bistable InGaAsP / InP DH laser under optical injection which produces optical bistability and optical amplification. The bistability of pin-pout for lasers with CW or pulsated operation is shown and some analyses for the results are given.

本文发表在《半导体学报》，第9卷，第1期，1988年1月

**InGaAsP / InP CCTS 双稳态激光器的纵模及偏振特性**  
**Polarization and Longitudinal Mode Characteristics of**  
**InGaAsP / InP CCTS Bistable Laser**

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本文给出了 InGaAsP / InP CCTS 双稳态激光器的模式特性。通过实验得到对双稳态激光器来说其吸收区的存在，使其对偏振及纵模的选择有一定的作用，使得 TM 模的输出强度在总输出中占的比例更小，及在双稳区内给出单纵模输出。

This paper gives the polarization and longitudinal mode characteristics of a InGaAsP / InP CCTS bistable laser. It is concluded that the saturable absorber plays major role in selecting the cavity mode operation in bistable laser. Its major effect is on the mode discrimination and mode group operation, i.e., TE or TM.

本文发表在《半导体学报》，第11卷，第10期，1990年10月

**GaAs / GaAlAs 半导体淬灭型光学双稳现象的实验研究**  
**Experimental Investigation on Optical Bistable Phenomena Caused**  
**by Laser Quenching Effect in GaAs / GaAlAs Semiconductor Lasers**

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在研究 GaAs / GaAlAs 半导体激光器淬灭效应过程中，我们发现其中一种结构的淬灭型半导体激光器的输出表现为一对共轭的双稳特性。我们认为，这种双稳现象是由共腔双波导模式淬灭效应引起的。

The output characteristics of one kind of the semiconductor lasers used to study quenching effect show a pair of conjugate bistable curves. This phenomenon may be caused by a laser quenching effect between the two modes of the co-cavity two waveguides.

本文发表在《半导体学报》，第11卷，第9期，1990年9月

**CCTS 结构 GaAs / AlGaAs 单量子阱双稳态激光器**  
**GaAs / AlGaAs Single Quantum Well (SQW) Bistable Laser**  
**with CCTS Structure**

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本文报道了 GaAs / AlGaAs 单量子阱 (SQW) 双区共腔 (CCTS) 结构的双稳态激光器, 给出了增益区和吸收区分别注入电流时的三端器件结构, 并在脉冲工作下得到了双稳特性。

This letter reports a GaAs / AlGaAs single quantum well bistable laser with CCTS structure. The bistability is demonstrated in the laser by injected currents into gain section and loss section, respectively.

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**双区共腔双稳激光器超短光脉冲输出特性分析**  
**Analysis of Ultra-Narrow Light Pulse Characteristics in a Semiconductor**  
**Laser with Common Cavity Two Sections Structure**

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本文采用速率方程讨论了双区共腔双稳激光器获得超短光脉冲的方法及特点。结果表明, 采用一般的电脉冲触发, 利用双稳激光器的 Q 开关长延时特性, 能够获得质量较高的超短光脉冲。

Based on the rate equations, the analysis of the transient behavior which leads to a method for obtaining ultra-narrow light pulse is given. It shows that owing to strong Q-switch and long delay effects in the device, a better quality ultra-narrow light pulse under electric current injection can easily be achieved in comparison with that in a normal DH laser.

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**GaAs / GaAlAs 光双稳激光器稳态及动态特性的实验研究**  
**Experimental Investigation of Static and Dynamic Characteristics in a**

## GaAs / GaAlAs Common Cavity Two Sections (CCTS) Bistable Laser

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本文报道了 GaAs / GaAlAs 侧向增益波导限制双稳激光器的静态及动态实验结果, 对 L-I 特性, 通态模式竞争、延迟特性、张弛振荡、有脉动、混沌现象等进行了研究, 并对结果进行了讨论。实验表明, 对于双区共腔双稳激光器, 由于腔内可饱和吸收体的存在, 使得其稳态及动态特性比普通均匀注入激光器复杂。与之有关的物理研究尚待进一步开展。

The static and dynamic characteristics of a GaAs / GaAlAs bistable laser with lateral gain waveguide confinement, including L-I characteristics, mode competition during switching on, long delay, ultrafast light pulse, self-sustained pulsation, chaos etc., are reported and discussed. It shows that for a CCTS laser with a saturable absorber in the cavity, the dynamic and static characteristics behave more complicated in comparison with that of a normal uniform injection laser, which demand a further analysis theoretically.

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## 双区共腔双稳态激光器电注入下特性的计算机模拟

### Computer Simulation for Characteristics of a CCTS Bistable DH Laser at Electric Injection

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本文对双区共腔半导体双稳态激光器在电注入下的稳态及瞬态特性进行了计算机模拟, 这种模型产生双稳和自脉动现象的机制是不均匀电注入本征可饱和吸收特性。我们研究了与可饱和吸收有关的几个参数  $\gamma$ 、 $\xi$ 、 $J_1$ 、 $J_2$  对双稳及自脉动现象的影响。

The computer simulation for stable characteristics and transient response of a CCTS bistable DH laser at electric injection is reported. The source of producing bistable behaviors and self-pulsation is intrinsic saturable absorber due to non-homogeneous injection currents for this model. Some parameters which affect self-pulsation and bistability are investigated, these parameters with relation to saturable absorber are spontaneous emission factor, input normalized currents  $J_1$ ,  $J_2$  for gain and absorbed sections, respectively.

本文发表在《半导体学报》, 第 9 卷, 第 1 期, 1988 年 1 月

## 双区共腔双稳态激光器在光注入下的计算机模拟 Computer Simulation for Characteristics of a CCTS Bistable DH Laser at Optical Injection

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本文对双区共腔半导体双稳态激光器在从吸收区背面及沿轴向外部光注入下的稳态及瞬态特性进行了计算机模拟, 得到稳态光开关及光放大特性。瞬态情况下随着注入光的增强, 输出由近混沌状脉动到单峰快衰减弛张弛振荡, 而更强光注入时, 则仅存在一延迟过程。

The results of computer simulation for stable characteristics and transient response of a CCTS bistable DH laser which is applied by the crosswise light injection or the axial injection are reported. The characteristics of light-switching and light-amplification at stable-state, and an output pulsation of chaos at weak incident light intensity, an approximately single peak with fast damped oscillation at strong light intensity and an ordinary delay process at stronger incident light intensity at transient response are obtained.

本文发表在《半导体学报》, 第9卷, 第1期, 1988年1月

## 单腔双接触结构激光器双稳特性研究 Investigation of Bistable Characteristics of a Semiconductor Laser with Single Cavity and Double Contacts

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本文从多纵模速率方程出发, 在取定考虑有K选择的抛物带间吸收, 增益系数的基础上, 采用数值方法, 对单腔双接触结构激光器的双稳特性的产生机理, 以及影响它的两个最主要参数(即双稳区注入宽度和开关时间)的各种因素作了系统的分析。

稳态分析结果表明, 多纵模的工作状态将使双稳区注入宽度减少, 而减少吸收区电注入或增大吸收区体积等可使双稳区注入宽度增大。瞬态分析结果表明, 双稳开关过程可分为两个阶段: 第一阶段谱宽大并伴有大幅度跳模; 第二阶段占时较长, 对双稳开关时间有较大影响, 可通过加大增益区电注入来减少振荡衰减时间。

本工作为设计双稳器件、提高器件性能提供了基础。

This paper reports on the bistable behaviour of a laser with a single cavity and double contacts calculated numerically on the basis of the consideration of interband absorption



with K selection rule starting from the multimode rate equations. Systematic analysis of various factors which effect the two important parameters of the device (width of the bistable injection region and response time) is also reported.

本文发表在《半导体学报》，第7卷，第2期，1986年3月

### **GaAs / GaAlAs 多量子阱激子吸收谱**

#### **Exciton Absorption Spectra of MQW Structures**

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在 10K 至 292K 温度范围内测量了 GaAs / GaAlAs 多量子阱结构的激子吸收谱。观察到轻、重空穴对应的激子吸收峰 (LH 和 HH) 及台阶状态密度。研究了轻、重空穴激子吸收峰的能量间隔及激子吸收峰的温度特性。发现多量子阱样品的 LO 声子展宽系数为 6.1meV, 比体 GaAs 的展宽系数略小。样品用国产 MBE 设备生长, 采用化学选择腐蚀技术除去 GaAs 衬底。

The exciton absorption spectra of GaAs / GaAlAs MQW structures at temperatures between 10k to 292k are measured. The exciton absorption resonances (HH and LH) and step accumulative density of state have been observed. The energy differences between light hole and heavy hole exciton absorption resonances have been investigated. We also investigated the temperature dependence of the linewidth of HH exciton absorption resonance. The LO phonon broadening constant  $F_b$  in our sample is 6.1 meV which is smaller than that of the bulk GaAs. The GaAs / GaAlAs MQW structures of 120 periods are grown on [100] oriented Cr-doped GaAs substrate by MBE in the institute of semiconductors of Chinese Academy of sciences. The GaAs substrate is removed by selective chemical etching, leaving the MQW structures exposed over 1mm<sup>2</sup> area.

• 本文发表在《半导体学报》，第10卷，第11期，1989年11月

### **GaAs / GaAlAs 量子限制 Stark 效应及自电光双稳现象的实验研究**

#### **Experimental Investigation on GaAs / GaAlAs Quantum Confined**

#### **Stark Effect and Self Electro-Optic Bistable Effect**

吴荣汉 段海龙 曾一平 王启明 林世鸣

孔梅影 张叔生 江德生 谢茂海

(中国科学院半导体研究所)

我们研制了 GaAs / GaAlAs 多量子阱 pin 结构的 SEED 器件。分析了器件的光电流光谱、光电流-电压特性。对于如何实现器件光学双稳态工作的有关问题进行了讨论。

A GaAs / GaAlAs Self Electro-optic Effect Device (SEED) with MQW pin structure has been fabricated. The measurement and analysis of the photocurrent spectrum, photocurrent-voltage Characteristics and photocurrent bistability are given. A discussion on the realization of its bistability is also concerned.

本文发表在《半导体学报》，第 11 卷，第 9 期，1990 年 9 月

### **GaAs / GaAlAs 多量子阱自电光效应光学双稳态**

#### **Optical Bistability in a GaAs / GaAlAs Multi-Quantum Well (MQW) Self-Electrooptic Effect Device (SEED)**

吴荣汉 段海龙 王启明 曾一平

孔梅影 潘 钟 张权生 林世鸣

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采用国产分子束外延系统生长的 GaAs / GaAlAs 多量子阱材料，成功地制备出室温自电光效应 (Self Electrooptic Effect) 光学双稳态器件 (SEED)。报道了这种器件在对称工作 (S-SEED) 和非对称工作时的光学双稳态特性。

Based on a GaAs / GaAlAs MQW pin structure grown by a home made MBE system in China, we have successfully fabricated SEED. The optical bistability and related properties of the device under symmetric operation (S-SEED) and asymmetric operation are reported.

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### **BILED / BILD 组合回路的光学逻辑运算**

#### **Optical Logic Implementation in Composite BILED / BILD Circuits**

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(哈尔滨工业大学应用物理系)

利用双稳态激光二极管或发光二极管回路 (BILD / BILED) 的组合，得到了光学多稳态、光学异或逻辑门和光学 R-S 触发器。光学多稳态可由 BILD / BILED 回路简单

地串联或并联得到。一个  $N$  稳态回路仅含  $N-1$  个 BILED 或 BILD 回路的串联或并联。实验上演示了三稳态和四稳态。光学异或逻辑门和光 R-S 触发器可由两个 BILED 或 BILD 回路并联, 通过选择不同的开启阈值和反馈系数构成。这种光电子混合的光学逻辑回路与大规模集成技术完全相容, 因此有希望应用于光学信息处理、光通信和光计算。

Optical multistability, optical exclusive-OR logic gate and R-S flip-flop have been demonstrated using the composite optoelectronic hybrid bistable laser diode or light emitting diode (BILD / BILED) circuits. The optical multistabilities can be easily obtained from the parallel or serial connections of BILD's or BILED's. A  $N$ -stable circuit only consists of  $N-1$  BILD or BILED circuits. Experimental results have demonstrated tristability and four-stability. Optical exclusive-OR logic gate and optical R-S flip-flop can be constructed by two parallel connected. BILD or BILED circuits, with different switching powers and feedback coefficients. This kind of optoelectronic logic circuits are fully compatible with VLSI technique and therefore promising for the application to optical signal processing, optical communication and optical computing.

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## 光电子混合多值逻辑

### Optoelectronic Multiple-Valued Logic Implementation

刘树田 李淳飞 吴杰 刘玉东

(哈尔滨工业大学应用物理系)

本文首次提出了一个利用双稳态激光二极管或双稳态发光二极管 (BILD / BILED) 回路构成光电子混合多值逻辑的方法。在该三值逻辑设计中, 我们利用由两个双稳态发光二极管回路构成的三稳态开关回路作为基本的“光电流镜”元件, 实验演示了三值逻辑中五种最基本的逻辑操作, 即: 补、最大、最小、右循环移位、文字。其他基本的逻辑门和任意的三值逻辑函数均可由“光电流镜”元件和以上给出的五种基本逻辑操作组合完成。基数不同的其他的多值逻辑系统也可利用这种方法实现。本文已被国内外同行引用。

A design for optoelectronic multiple-Valued logic circuits that uses bistable laser diodes or light emitting diodes (BILD's or BILED's) is reported. In this multiple-valued logic design, an optoelectronic tristable switching circuit, or photo-current mirror, in which two bistable light emitting diodes are connected in parallel serves as the basic logic element. Five ternary logic implementations: complement,  $\text{Max}(x,y)$ ,  $\text{Min}(x,y)$ , Cycle, and Literals, have been demonstrated experimentally. Furthermore, any ternary logic function can be

generated with the photo-current mirror elements and the five logic primitives mentioned above. Other multiple-valued logic system with the different radix can also be realized using the same method.

本文发表在 OPTICS LETTERS, Vol.14, No.14, PP713-715, 1989 年

## 由光电子回路构成的可编程光学阈值逻辑 Programmable Optical Threshold Logic Implementation with an Optoelectronic Circuit

刘树田 吴杰 李淳飞  
(哈尔滨工业大学应用物理系)

我们利用一个光电子回路演示了光学二进制阈值逻辑操作。由于这一阈值逻辑门的权重和阈值均可取正值和负值, 因而该阈值逻辑门自身便构成了一个逻辑完备集。该逻辑门的权重和阈值信号都可用光学信号进行动态的可编程地控制, 因此可完成实时的逻辑操作。并且由于在该逻辑门的设计中首次提出了一种有别于传统阈值逻辑门那种“相乘”加权的“取最小值”加权方法, 因而使得该阈值逻辑门具有明显的容许输入信号幅值波动的能力。利用单个逻辑门, 实验上演示了三个信号输入时的与、或、多数表决和其他一些任意的逻辑函数。本文还讨论了该阈值逻辑门在神经网络计算和二维并行逻辑处理中的应用。

We demonstrate optical binary threshold logic by using an optoelectronic circuit. This threshold logic gate is in itself a logical complete set owing to the availability of both positive and negative weights and threshold. The weights and the threshold signals are all optically addressed and dynamically programmed, thereby providing real-time operation. Furthermore, we present, for the first time a new weighting process which we name it as “minimization weighting process”. This weighting process is quite different from the conventional ones in which the weighting process is realized by the inputs being multiplied by the weighting parameters. Therefore this optoelectronic threshold gate can tolerate the variabilities of the input signals. Experimental results demonstrate AND, OR, MAJORITY functions and three other arbitrary logic functions for three input signals with a single gate. Applications in neural computing and two-dimensional parallel logic processing are discussed.

本文发表在 OPTICS LETTERS, Vol.15, No.12, pp.691-693, 1990

## 光电子可编程阈值逻辑和模糊逻辑

## Optoelectronic Implementation of Programmable Threshold

### Logic and Fuzzy Logic

李淳飞 刘树田 吴杰

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本文首次提出了一个新颖的、具有对称性结构的可编程光电子混合阈值逻辑门。该门可带有双极输出,与一个或门级联可以得到多种线性可分和非线性可分的逻辑函数。该逻辑门可应用于可编二维并行的逻辑处理,并且可实时地实现时序逻辑处理中所必需的各种触发器。本文首次提出用简单的光电子回路完成光学模糊逻辑的设计,实验上演示了模糊补、最大、最小和限界差四种逻辑运算。给出了一个多功能的、可编程的模糊逻辑门,利用该逻辑门可实时地完成七种模糊逻辑操作。

For the first time, we present a new, architecturally symmetric programmable optoelectronic threshold logic circuit. This threshold logic gate can have bipolar output, and therefore it can implement both the linearly separable and the nonlinearly separable logic functions, with a cascade OR gate. This optoelectronic threshold logic gate can be used to programmable two-dimensional parallel logic processing and also to perform the flip-flops that are necessary for sequential logic processing. In this paper, we present, for the first time, the optical fuzzy logic design that uses simple optoelectronic circuits. Experimental results have demonstrated the fuzzy Complement, Maximum, Minimum and Bounded-difference. We also have proposed a multi-functional, programmable fuzzy logic gate that can implement seven basic fuzzy logic functions in real time.

本文发表在“1990 日本国际光计算专题会议”, 1990 年 4 月, 及会议论文集 Post-deadline papers, pp. 15-16

### 用于并行和时序处理的光电逻辑回路

#### Optoelectronic Logic Circuit for Parallel and Sequential Processing

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(哈尔滨工业大学应用物理系)

本文提出了一个具有双输出的光电阈值逻辑回路。由该回路与一个或门级联,得到了两个变量输入时所有的 16 种布尔逻辑函数,因而该回路可以应用于二维可编程实时并行处理。本文同时给出了利用该回路完成时序逻辑处理中触发器,即: R-S、D、主从、T 和 J-K 触发器的设计,并给出了 R-S 触发器的实验结果。

In this paper, we present a double output optoelectronic circuit. All the 16 kinds of

Boolean logic functions are demonstrated by using the circuit and a cascade OR gate. This logic circuit can be used in programmable real-time two-dimensional parallel logic processing. We also present, in this paper, the designs of the optical flip-flops, such as R-S, D, Master-Slave, T and J-K flip-flop, for optical sequential processing. Experimental results of the R-S flip-flop is presented.

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### 由光电子混合双稳态回路构成的可编程二进制光学阈值逻辑

#### Programmable Binary Optical Threshold Logic Implementation via an Optoelectronic Bistable Circuit

刘树田 吴杰 李淳飞

(哈尔滨工业大学应用物理系)

本文利用光电子混合双稳态发光二极管回路 (BILED)，通过调节电阻的方法来实现对输入信号的加权和对权重和的取阈，构成了一个可编程的光电子混合阈值逻辑门。实验上得到了三个信号输入时的与、或、“多数表决”和一些其他的逻辑函数。本文就实验中所遇到的如不能实现正负两种加权和取阈以及输入容量低等问题进行了分析，并提出了一个用光信号进行加权和取阈的方案。该阈值逻辑门可同时解决以上两个困难。

In this paper, we present an optical programmable threshold logic gate using an optoelectronic bistable light emitting diode circuit. The weighting and thresholding processes are performed by adjusting the resistances. Some preliminary experimental results of AND, OR, MAJORITY and other arbitrary logic functions are given for three input case. The problems that exist in the experiment, such as the inapplicability of both positive and negative weights and threshold, and lower inputs capacitance, are discussed. Another scheme of programmable threshold logic circuit with optical signals for weighting and thresholding is proposed in order to overcome the problems above.

本文发表在“1989年美国光学学会年会”，Orlando, paper ThT22, 1989年10月

### 由组合双稳态发光二极管回路构成的光学多值逻辑

#### Optical Multiple-Valued Logic Using Composite Bistable Emitting Diode Circuits

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(哈尔滨工业大学应用物理系)

本文首次提出了用组合双稳态发光二极管回路构成的光学多值逻辑门的设计。分析了由两个双稳态发光二极管回路构成的“光电流镜”的工作原理,给出了三值逻辑中补门和最大门的实验结果。讨论了利用“光电流镜”作为基本的逻辑单元构成其他基本逻辑运算的可行性。

We present, for the first time, the optical multiple-valued logic design using the composite bistable light emitting diode circuits. The operation principle of the “photo-current mirror” formed by two parallel connected BILED's are analyzed. The experimental results of ternary Complement and Maximum are given. The possibility of obtaining other basic ternary logic functions with the “photo-current mirror” as the fundamental element are also discussed.

本文发表在《1989年国际光计算专题会议会议论文集》,及 Optical Computing, 1989 Technical Digest Series, Vol.9, pp. 236-239

## 由激光二极管或发光二极管混合双稳态回路构成的光学全加器与多值逻辑门

### Optical Full Adder and Multiple-Valued Logic Gates Using Bistable Laser Diode or Light Emitting Diode Circuits

刘树田 刘玉东 王瑞波 吴杰 李淳飞

(哈尔滨工业大学应用物理系)

首次利用光电子混合双稳态发光二极管回路构成了一个光学二进制全加器。该全加器仅含三个并联的双稳态发光二极管回路,因而具有结构简单,稳定性好等特点。本文还介绍了利用双稳态发光二极管回路构成的光学三值逻辑设计,较详细地给出了三值逻辑门设计的基本单元——“光电流镜”和三值“补”门的工作原理。

In this paper, an optical binary one-bit full adder that uses the optoelectronic hybrid bistable light emitting diode circuits is presented, for the first time. This optical binary full adder only consists of three parallel connected bistable light emitting diode circuits, and thus it is architecturally simple and stable. The new design of optoelectronic ternary logic implementations using the bistable light emitting diode circuits are also introduced in this paper. The operation principles of the “photo-current mirror”—the basic element in our multiple-valued logic design, and the ternary Complement gate are discussed in detail.

本文发表在《1989光电子器件与集成技术年会论文集》,第368~370页

## 电光导波 Mach-Zehnder 干涉调制器的研制近况

### Current Informations on the Fabrication of Guided-Wave Mach-Zehnder Modulators

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(上海交通大学)

我们研制光学 A/D 转换器的基本部分是 M-Z 调制器阵列的集成光路, 其电气部分为集总参数 RLC 等效电路, 我们了解了目前的一些进展情况以有助于工作。

1. R.A. Becker 等用单模三导向分叉的相干耦合弯头作成了五路分支光路, 降低了 M-Z 调制器中多个 Y-分叉光波导的传输损耗。

2. 用“热稳定”法处理扩 Ti 调制器, 大大降低器件由于光损伤导致的长时间不稳定性。

3. 改进调制电极结构, 使 3dB 带宽达 7.3GHz。

4. Duchet 用新的电极设计图形, 将半波电压降低到 0.35V。

We are currently engaged in an effort to improve further the optical A/D converter characteristics such as optical insertion loss and band width of the modulator array, the following reports are very beneficial to us.

1. R.A. Becker's report on a single-mode five-way branching circuit that utilizes a new single-mode three guide fork as well as coherently coupled bends to achieve 80% optical transmission.

2. A thermal fixing technique to improve the temporal stability of  $\text{LiNbO}_3$  channel waveguide modulators.

3. In a lumped circuit M-Z interferometer, a “center tapped” electrode of the same active length as the end-tapped ones obviously extends the band width of modulation.

4. With a new electrode configuration, the half-wave voltage of a M-Z modulator can be reduced to 0.35V.

本文发表在《第三届全国纤维光学与集成光学学术交流会论文集》, 湖南大庸, 1988 年 10 月

## Ti:LiNbO<sub>3</sub> 条波导 Fabry-Perot 二位模数转换器

### Two-Bit Analog-to-Digital Conversion Using Ti:LiNbO<sub>3</sub> Channel Waveguide Fabry-Perot Modulator Array

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(上海交通大学)

LiNb<sub>3</sub> 扩 Ti 条波导 F-P A/D 转换器的集成光路是在 X-切割 LiNbO<sub>3</sub> 衬底上通过



光刻、溅射、抬离、扩 Ti 等工艺制成条波导,然后将波导的两端面仔细地抛光成 F-P 腔,再通过蒸铝、套刻、腐蚀等工艺,在波导两端作上电极。波导宽  $9\mu\text{m}$ , 间距  $500\mu\text{m}$ , 电极宽  $240\mu\text{m}$ , 间距  $23\mu\text{m}$ , 电极长 LSB10mm MSB5mm, 调零 2mm。

测试结果: 半波电压 12V (LSB), 23V (MSB)。

输入三角波信号时,经波导输出正弦波形的调制光,再经电压比较器输出对应数字信号“1”与“0”的高、低电平。激光波长  $0.63\mu\text{m}$ 。

Through previous work on constructing a F-P channel waveguide modulator, we are now trying to fabricate a 2-bit channel A/D converter that makes use of a F-P modulator array. The integrated circuit is constructed from x-cut  $\text{LiNbO}_3$  crystals as the substrate utilizing conventional microfabrication process. In addition, the optical input and output end faces of the substrate are very carefully polished for multireflection. The waveguide width is  $9\mu\text{m}$  and the electrode lengths are 10mm and 5mm respectively for the LSB and MSB channels. Experimental results illustrating the periodic dependence of the modulator output on applied ramp voltage test signal that indicate the half wave voltages are 12V and 23V respectively for the LSB and MSB channels. Subsequently the output light signals are sent to a voltage comparator to generate the digital outputs.

本文发表在《中国光学学会第四届集成光学学术交流会议论文集》,成都,1987年10月

## Mach-Zehnder 条波导两位电光模数转换器

### Prototype of an Integrated-Optics Two-Digit Analog-to-Digital Converter Using Mach-Zehnder Modulator Array

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(上海交通大学)

经过数年探索,我们选用 M-Z 调制器阵列作为光学 A/D 转换器的主体结构,作成了两位转换样品并进行了初步测试。调制器阵列是在 X-切割  $\text{LiNbO}_3$  基片上以通常的微加工技术制成条波导宽  $6\mu\text{m}$ , 低位与高位调制电极长度分别为 16mm 与 8mm。波长  $0.63\mu\text{m}$  的激光通过器件时,受到 10kHz 三角波信号电压的调制。低位与高位的半波电压分别为 6V 与 13V, 调制度分别为 45% 与 63%。

A 2-bit A/D converter integrated circuit is constructed and tested for demonstration. The M-Z modulator array is fabricated on x-cut  $\text{LiNbO}_3$ . The waveguide width is  $6\mu\text{m}$  and the electrode lengths are 16mm and 8mm respectively for the LSB and MSB channels. Response to a ramp test signal applied to the sample indicates that the halfwave voltages are 6V and 13V, and the modulation depths are 45% and 63%.

respectively for the LSB and MSB channels.

本文发表在《第五届全国集成光学学术讨论会论文集》，上海，1989年10月

### 低温度 ZnSe / ZnS 多量子阱光学双稳态 Optical Bistabilities in ZnSe / ZnS Multiple Quantum Wells at Low Temperature

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申德振 \* \* 范希武 \* \* 范广涵 \* \* 陈连春 \* \*

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我们在 77K 温度下，观察了 ZnSe / ZnS 多量子阱的激子吸收及激子带展宽现象。在不同的激发波长处进一步得到了增强吸收双稳和色散型双稳态。非线性机制为激子带展宽。

Excitonic absorption and the excitonic band broadening are observed in ZnSe / ZnS multiple quantum wells at 77K, and the increasing absorption and dispersive optical bistabilities are obtained at different excitation wavelengths. The nonlinear mechanism is the excitonic band broadening.

本文发表在《中国激光》，第 17 卷，第 9 期，1990 年

### 硅晶体中的二次混合与相干放大 Two Wave Mixing and Coherent Amplification in Si Crystals

杨向明

(哈尔滨工业大学应用物理系)

两束强度不等、波长为  $1.06\mu\text{m}$  的脉冲激光在硅晶体中混合，产生一个瞬态受激光栅。通过晶体后，发生能量从强光束向弱光束转移的现象，从而使弱光束的强度得到放大。实验中得到  $G=5$  倍的放大率。

Two laser beams with  $\lambda=1.06\mu$  and different intensities mixing in Si crystal, generate a transient induced grating. After the Si crystal, energy can be transferred from the high intensity beam to the low intensity beam, thus giving rise to an amplification of the weak beam. In this paper, the experimental condition for this effect was studied, a  $G=5$  amplification was achieved under optimized conditions.

本文发表在《中国激光》，第16卷，第1期，1989年

## ns 与 ps 激光脉冲在硅晶体中的相干放大 Coherent Amplification of ns and ps Pulse in Si Crystals

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(哈尔滨工业大学应用物理系)

本文报道了 ns 与 ps 脉冲光在硅晶体中的二波混合与相干放大。用 ns 脉冲可得到 5~8 倍的时间平均增益，用 ps 脉冲可得到约 14 倍的时间平均增益。增益与两光束强度之比及泵浦光强度有密切关系。

In this paper we report the two wave mixing and coherent amplification of ns and ps pulse in a Si crystal. G is 5-8 times with ns pulse and 14 times with ps pulse. G is intensive dependent on the incident beams intensity ratio and the pump beam intensity.

本文发表在“1989 年光电子年会”

## BSO 晶体生长和 PROM 的制备研究 Study on Crystal Growth of BSO and Fabrication of PROM

徐良瑛 束碧云 肖兵

(中国科学院上海硅酸盐研究所)

PROM(Pockels Readout Optical Modulator)是一种固态的、光学寻址的、可反复迅速写入、读出、擦除和存储二维数字信息及具有各种灰度等级模拟图像的空间光调制器。目前，在实时光学信息处理和光学计算领域中，仍旧认为是具有实际应用价值的空间光调制器之一。

本文介绍了我们从化学计量熔体中用提拉法生长 BSO 晶体和 PROM 的制备、结构、特性和应用即非相干光至相干光图像转换、对比度反转、边缘增强的实验结果。

PROM(Pockels Readout Optical Modulator) is a solid state, rapidly recyclable spatial light modulator, which can be addressed optically and utilized for storage, write-in and read-out of two-dimensional digital signals as well as analogous images of different grey scales. Up to now it is still regarded to be one kind of the spatial light modulators of practicable use in the field of real-time optical signal processing and optical computing.

In this paper some experimental results on BSO crystal growth from stoichiometric

melt by Czochralski method and fabrication, structure, characteristics and application e. g. incoherent-to-coherent image conversion, contrast inversion, edge enhancement of PROM are presented.

本文发表在《1989 光电子器件与集成技术年会论文集》和 Topical Meeting on PHOTOREFRACTIVE MATERIALS, EFFECTS AND DEVICES II. January 17-19, 1990, Aussois (France)

### 光双稳器件皮秒响应机制研究

#### Research on Mechanisms of ps Response for the Optical Bistability Devices

周 毅 龚小成 陈益新

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对于光学双稳器件,有可能在腔失谐和原子体系失谐的情况下获得从开到关的皮秒响应。其微观机制系由于激子极化激元间以及极化激元与晶格振动(声子)间的相互作用起了决定作用。本文论述了决定其动力学弛豫过程的因素不是简单地源于固体中载流子(电子和空穴)的激发、迁移、碰撞及复合等过程,而是以载流子、声子和光子互相耦合的形式形成极化激元,极化激元间的碰撞以及极化激元与晶格的相互作用决定了材料弛豫的微观过程。

It is possible to obtain the ps response from open state to close state for the optical Bistability devices under misresonance of cavity and atom systems. The microscopic mechanisms are essentially decided by the interaction between the exciton-polaritons and between the polaritons and lattice vibrations (phonons). In this paper, the mechanisms for the dynamic relaxation process is considered. It is not simply based on the process of excitation, mobile, collision and recombination of the carriers (electrons and holes) in solid state and is related to the collisions between the polaritons which are formed by the mutual coupling of carriers, phonons and photons and to the interactions between the polaritons and phonons.

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### 一种利用光学符号代换法则实现并行光学多值运算的方法

#### A Method of Parallel Optical Multiple-Value Operation Based on Symbolic Substitution Rule

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(清华大学精密仪器系)

本文叙述了一基于符号代换法则去实现并行光学多值运算的方法。演示此种算法的试验装置,包括一马赫干涉仪、NOR 门阵列与编码解码掩模。

多值输入在计算前首先进行编码,然后将二输入图形叠加,经识别与代换,最后可同时得到和与进位项。试验中采用了两个三重矩阵,使用了一个计算全息制作的分束器,用以提高信噪比。

The experimental device for demonstrating this algorithm consists of a Mach-Zehnder interferometer, a NOR gate array, coding and decoding masks.

The multi-value input is encoded before calculation, then the two input patterns are overlapped, after recognition and substitution, the result of sum and carry can be obtained simultaneously. The experimental results of two ternary  $3 \times 3$  matrixes are given. A computer-generated beam splitter is used for enhancing the signal to noise ratio.

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### BSO-PROM 的光学逻辑功能及其应用

#### Optical Logic Operation of BSO-PROM and Its Applications

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本文讨论了对输入图形进行特定的编码和对器件采用不同的读写模式。仅用单个 BSO-PROM ( $\text{Bi}_{12}\text{SiO}_{20}$  单晶普克尔效应光读出器件)便实现了两个二值图形间的所有 Boolean 逻辑,而且不需要时序地改变器件的外加电压(极性和大小),从而大大提高了 PROM 用于光逻辑运算的速度。还可将这种 PROM 成功地用于光学符号代换、矩阵外积及互连网络之中。

A special coding for input patterns and different read/write for BSO-PROM (Pockel's read-out optical effect modulator) are discussed. Only a single BSO-PROM device is needed to realize all the Boolean logic between two binary patterns. The sequential changes of the bias voltage (polarity and amplitude) are avoided, so that the logic operation speed with PROM is greatly raised. The applications of BSO-PROM for OSS (optical symbolic substitution) MOPC (matrix outer product calculation) and NI (network interconnection) are also implemented.

本文发表在《半导体光电》，第10卷，第2期，1989年

### 光学脉动进位多比特全加（减）器

#### Optical Ripple Carry Multi-Bit Full-Adder (Subtractor)

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本文提出了利用光学符号代换法则和脉动进位原理实现进位超前光学多比特全加（减）器，其特点是不需要任何实时器件来存储中间结果，所以结构简单、速度快，并且可以实现由多比特二进制数所组合的矩阵间的加（减）法。

In this paper, we propose a kind of system which based on optical symbolic substitution rule and ripple carry propagation principle to implement look-ahead optical multibit full-adder (subtractor). The characteristic is that it is of simple structure and high speed for no inter-mediate results to be stored by any real-time device, and can implement multibit binary matrix addition (subtraction).

本文发表在《应用激光联刊》，第8卷，第4期，1989年

### 三输入二输出光学并行逻辑处理系统

#### Triple-In Double-Out Optical Parallel Logic Processing System

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(清华大学精密仪器系)

本文介绍了一种基于铸影法的三输入二输出光学逻辑运算系统，可以对三输入的256种逻辑进行运算。此种光学相加器极易于实现对输入图形实时进行编码。

此种处理器的缺点是，光效率低、需预先进行编码和难于获得级联，但由于它具有高平行处理的性质，故首先可用于图像处理和模式识别中。

A triple-in double-out optical logic operating system based on shadow-casting processing is described, All the 256 logic operations of three inputs can be performed, and the optical adder can be easily implemented. A real-time encoding method for the input patterns is also presented.

The disadvantages of this kind of processor are low light efficiency, the need for pre-encoding processing, and difficult in achieving cascaded operation. However, because of its high parallel-processing capability, its first applications may be found in image pro-

cessing and pattern recognition.

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### 多光束分光光栅的优化设计

#### Optimization of Grating Multi-Beamsplitters

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文章导出一计算二维光栅结构的数学解法。它可求得设定谱的精度达百分之一。试验证明, 我们所制出的光栅可将一平面波转化为中心矩阵为  $11 \times 11$  的等光强衍射光波。

此文所述及的优化方法, 可成功地用于全息分束器的结构设计, 它可求出任意设定的谱。所设计的优化程序可在一个人计算机上运行。设计出各转化点的位置精度均可优于通常的制造精度, 故制造精度为限制空间谱的主要因素。

We derive a numerical method for calculating binary grating structures, which has predetermined spatial spectra with a typical accuracy of less than one percent. As an experimental verification, we present test results of a grating that converts a plane wave into a central block of  $11 \times 11$  uniformly diffracted waves.

The optimization method presented in this paper was found to be successful in design of holographic beamsplitter structures, which give arbitrary predetermined spectra. The optimization program we prepared is efficient enough to be run in a personal computer, and it gives the transition point positions with an accuracy that is beyond most practical fabrication techniques, which therefore set the limit to the accuracy of the spatial spectra.

本文发表在《光学学报》, 第8卷, 第10期, 1988年

### 光学符号代换法则 (OSSR) 的应用研究

#### The Application of Optical Symbolic Substitution Rule

周少敏 王民强 邬敏贤 金国藩

(清华大学精密仪器系)

为了发挥光的超并行处理能力, 在光计算的研究中, 一种所谓的光学符号代换法则 (OSSR: Optical Symbolic Substitution Rule) 由 A. Huang 在 1983 年提出。它基于二维模式的相关识别和传递来完成各种所需运算, 现已得到人们极大的关注。本文将首先提出一种利用 OSSR 与改进的符号数值 (MSD: Modified Signed-digits) 算法来实现多元多位

数字矩阵运算的方法, 然后探讨 OSSR 在数字信号的可控传输、纠错编码通信以及人工视觉图像预处理中的应用可能性。

So as to perform the capability of highly optical parallelism, a so called the optical symbolic substitution rule was developed by A.Huang in 1983. Many operations based on two dimensional recognition and shifting can be performed, the technique has been highly respected by many scientists.

This paper provides a newly developed technique which combines the optical symbolic substitution with modified signal digits technique to perform multi-element multi-bit matrix calculation. The possibility of using OSSR approach in digit signal controllable transmission, code error correction in communication and preprocessing of artificial intelligence vision are also discussed.

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### 光学计算中的真值表查找法

#### Truth-Table Look-Up Method Used in Optical Computing

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(清华大学精密仪器系)

真值表查找法实现算术运算是一种并行算法, 它避免了常规算法中高位结果需要等低位进位才可得出, 而是通过查表一次得出结果。在通常的真值表查找法中, 为了避免真值表容量增加过快的缺点, 常常采用余数算法, 对输入进行余数编码, 但余数编码需要一个复杂的光学系统才能实现, 而编码变换本身又消耗了大量时间。在本文中, 我们提出了一个简单的方法来减少真值表的量。在实现加法时, 以每一位进位位作成真值表, 一次查表得出进位位值, 然后通过进位位与输入的“异或”得出结果。在乘法中, 把乘法分解成加法与乘方的混合形式, 以加法与乘方作为真值表进行运算。

文中介绍了使用一输入掩模与一真值表及一 PROM 普克尔效应光调制器组成的光学系统, 以及加、减、乘、乘方运算的试验结果。

Truth-table look-up method is one of the parallel computing algorithm to perform mathematical calculation and obtain the final result directly from the truth-table, which can avoid the disadvantage of conventional calculating approaches, in which the high bit result must be obtained from the carry of the lower bit term. In conventional truth-table look-up algorithm in order to avoid the fast increase of size of truth-table usually residue number algorithm is used for encoding the input, but a very complicated optical system is needed to perform such an encoding, and also it takes time. In this paper, we develop a



simple approach to reduce the size of the truth-table. In implementing the AND-operation, we set each carry term as the truth-table, hence the carry term can be obtained directly from the table, then the final result can be obtained from the carry and the XOR of the input. In multiplication, the multiplication can be resolved into the addition and the square then the result can be calculated out.

One input mask, one truth-table mask and a PROM are used to demonstrate the addition, subtraction multiplication and square optically. The experimental results are also shown.

本文发表在《1989年电子器件与集成技术年会论文集》

### 全光并行四比特乘法器

#### Pure Optical Parallel Four Bit Multiplier

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本文使用了 ZnSe 双稳元件, 做了些基本逻辑元件试验, 证明利用离轴斜入射光束可改变元件的透反射特性曲线, 合理地使用曲线的各部分, 将可用较少的器件组合成各种逻辑回路。离轴入射系统的缺点是功率损失大, 耦合与调整困难, 不易保证固定的严格的角度, 但若装卡稳定, 构成各种系统不是不可能的。

In this paper, some ZnSe bistability devices are used to implement several basic logic experiments. It proves that the off-axis beam can change the characteristic curve. Reasonable using different parts of the curve can largely reduce the quantity of devices used for performing logic circuits. The disadvantage of the off-axis system is high power loss, difficult to be coupled with different elements and maintain the angles required, but if it can be stable assembled, constructing different systems are not impossible.

本文发表在《1989年电子器件与集成技术年会论文集》

### 等光强分束器的设计与制造

#### Optimization and Fabrication of Grating Beamsplitter

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文中介绍了 Dammann 二维光栅型的等光强分束器的设计与制造。

为了找到合适的二元位相光栅结构,人们所用的数学方法有多种,但最成功的方法看来是扩展的拉格朗日函数方法及非线性优化方法,但在分裂的光束数很大的情况下,有时也得不到收敛的解。

文中还介绍了使用照相缩版、光刻、化学腐蚀制作此种分束器的方法及所得的实验数据。

In this paper, the design and fabrication of the two dimensional Dammann grating equal intensity beam splitter are introduced.

So as to achieve the proper structure of a binary phase grating, many mathematical methods have been introduced, of the most successful one is the Lagrangian function approach. The non-linear optimization is also one of the approaches, but if more splitted beams are needed, it is difficult to find the convergence of the solution.

In this paper, a more simplified algorithm that is to find the optimized solution from a group of nonlinear equations is introduced. Some useful solutions have been obtained, the corresponding beam splitter have been fabricated. The technique of photoreduction, photoetching and chemical etching to fabricate such kind gratings and experimental results are also introduced.

本文发表在《1989年电子器件与集成技术年会论文集》

## 体全息及互连元件的实验研究

### Experimental Research on Volume Holograms and Interconnection Devices

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(清华大学精密仪器系)

光学全息互连,是光学互连最重要的方式之一。它具有无滞延、并行性、自由空间传播、制作容易、体积小等优点,是最有可能获得实用化的互连方式。

重铬酸盐明胶(DCG)及其位相型体全息图,是研制全息互连元件的重要材料和手段。DCG全息图以它效率高、噪声小等许多优点而成为全息光学元件(HDE)的首选材料。开展DCG的应用研究是光计算课题中的重要基础工作,我们进行了一些初步的实验研究。

此文中,我们介绍了DCG记录材料及其性质、体全息分束器和全互连元件的研制。

Optical holographic interconnection is the most important one in optical interconnection. It has advantages of no delay, high parallelism free space propagation, easy to fabricate and small volume. It may be the most practical approach in

interconnection.

The DCG and phase volum hologram is the material and the approach for making optical holographic interconnection devices, DCG hologram has advantages of high efficiency, low noise etc., so it becomes the prior candidate for making HOEs.

In this paper, the DCG recording material and its property, volume holographic beam splitter and the perfect shuffle are introduced.

本文发表在《1989年电子器件与集成技术年会论文集》

### 真值表查找法光学处理器中的表量压缩研究

#### Table-Reduction in Truth-Table Look-Up Optical Processing

吴斌 邬敏贤 金国藩

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随着对计算机能力日益增长的需要,又燃起对真值表查找的新兴趣,但随着输入数字的增长,使真值表的表量大得不可想象。通常使用余数数学方法去解决此问题,但余数数学处理器缺点是产生时间滞后。

在此,我们提出一个简单的方法去减小相加与相乘的真值表方案,即以进位真值表去取代“和”的真值表,每一位的进位可同时以真值表查得,需用一个半加器求出最后结果。结果的每一位数是三输入的半加之和。此三输入为进位项、被加数和加数。对乘法来说,乘积可表示为“和”与“平方”的组合,因“平方”的真值表要比由乘积作出的表量小很多。在光学实现的试验中,我们使用了 PROM 作为逻辑器件,运算是基于图像识别,试验结果亦示于文中。

The increasing need of computing power has generated a renewed interest in truth-table look-up processing. But as the number of input digits increases the size of the resulting truth-table increases so fast that the required number of reference patterns may become unmanageable. Usually residue number system is used to solve this problem. However residue arithmetic processors suffer from several disadvantages. The most significant one is the time delay.

In this correspondence, we proposed a simple way to reduce the truth-table for addition and multiplication. Instead of producing sum's truth-table, a carry's truth-table is produced. Carries in each bit can be get simultaneously by truth-table look-up technique. To get the final result, a half-adder is required. Each bit of the result is the half-adder of three inputs, one is the carry, the other two are augend and addend respectively. In multiplication, the product is expressed as a composition of addition and square, the result truth-table of square are much smaller than the table directly constructed from product. In

the experiment, PROM is used as a logical device to implement logical based pattern recognition. Experimental results are also demonstrated.

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### **Bi<sub>12</sub>SiO<sub>20</sub> 晶体用于光并行逻辑运算时输出质量及写入灵敏度的分析**

Analysis on Output Quality and Write-In Sensitivity for Bi<sub>12</sub>SiO<sub>20</sub>

Optical Parallel Logic Operation System

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以 Bi<sub>12</sub>SiO<sub>20</sub> 晶体制成的实时器件 BSO-PROM, 可用于光并行逻辑运算。本文分析了影响其输出对比度、实际分辨率及写入灵敏度的因素; 并给出了获得高对比度、高灵敏度应满足的条件。

通过本文的分析可得出以下结论: 1. 为获得好的对比度, 在满足消光条件下, 还应满足  $\alpha = \pi / 4$ ,  $\beta = 3\pi / 4$  或  $\alpha - \beta = \pi / 4$ ; 2. 为达到高的写入灵敏度, 应从晶体的阴极方向写入; 3. 写入曝光量将影响读出图像的分辨率。

BSO-PROM made with Bi<sub>12</sub>SiO<sub>20</sub> crystal can be used for optical parallel logic operation. Analysis is made on these factors which has an impact on output contrast, actual resolution and write-in sensitivity. Conditions which will meet the needs for obtaining a high contrast and high sensitivity are given.

The following conclusions can be obtained: 1. In order to obtain better contrast, not only illuminating light condition must be satisfied, but also  $\alpha = \pi / 4$ ,  $\beta = 3\pi / 4$ , or  $\alpha - \beta = \pi / 4$  must be maintained; 2. So as to have high writing sensitivity, the writing beam has to be illuminated from the cathode direction of the crystal; 3. The writing exposure will influence the resolution of the image.

本文发表在《半导体光电》, 第 11 卷, 第 3 期, 1990 年

### **光学符号代换矩阵乘法器**

Matrix Multiplier Based on Optical Symbolic Substitution

周少敏 邬敏贤 金国藩

(清华大学精密仪器系)

光学矩阵运算在光数字计算中占有非常重要的地位, 光学上的许多变换与信号处理问

题均可化为一组基本的矩阵运算。本文提出了一种利用光学符号代换法则和矩阵外积算法来实现多比特矩阵相乘的方法。具有并行处理及扇入扇出 (fan-in fan-out) 特性的光学符号代换法是由 A.Huang 提出的, 但本文使用了一种多窗口解码掩模, 使操作的通道数大大减少。与一般的矩阵乘法相比较, 本法具有精度高和速度快的特点。本文还给出了二比特矩阵相乘的实验结果。

In this paper, a method of matrix multiplier is realized by using Optical Symbolic Substitution Rule (OSSR) and matrix outer product algorithm. The OSSR developed by A.Huang is optimized, the operation channels are greatly reduced by using multi-window mask. This new approach has advantages of high accuracy and calculating speed over conventional matrix multiplication. As an example, an experimental result of 2-bit matrix multiplition has been given.

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### 具有多逻辑功能的 ZnS 光学双稳态器件的研究

#### Research of Multi-Logical Optical Bistable ZnS Devices

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本文报道了我们利用 ZnS 光学双稳滤光片的反射和透射特性曲线, 有目的地选择滤光片的结构, 研究出在同一组光信号输入的情况下, 同时从反射光和透射光获得多逻辑输出的透反型光学双稳器件。从理论和实验两个方面探讨了干涉滤光片的结构, 特别是中间层厚度对透反型光双稳器件特性的影响, 找到了较为合理的结构参数。这种透反型多逻辑功能双稳器件的采用, 对设计各种光计算功能的实验是非常有益的。

In this paper, it is presented that we have developed the optical bistable ZnS multi-logic device by using the transparent and reflective characteristics of the interference filter at the same time. The structure of the filter is discussed in detail the influence of the thickness of spacer and the reflectivity of the stacks analysed based on the theoretical and experimental results. The utilization of the optically bistable multi-logic device is helpful for the demonstrating experiments of optical computing.

本文发表在《中国激光》, 第 7 期, 1990 年

### 一种实现二进制加法符号替换规律的光逻辑系统

## A Simple Optical Logic System to Implement Symbolic Substitution Rules of Binary Addition

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为了实现二进制加法符号替换规律, 本文提出了一种简单的光逻辑系统, 它仅包括一片二维阵列光学双稳器件。本实验采用同时具有 NXOR 和 OR 逻辑功能的透反型 ZnS 光学双稳干涉滤光片作光逻辑器件。该光学逻辑系统采用固定的自由空间互连方法, 具有光学硬件少, 光功率损耗低, 结构简单, 实用等优点。

For realizing symbolic substitution rules of binary addition, this paper proposes a simple optical logic system which includes only one 2-D array of optical bistable device. The optical bistable ZnS IF of transmission-reflection type which simultaneously has two logic function of NXOR and OR as optical logic device is used in this arithmetic system. The invariable free space interconnect is adopted in the optical system. Four symbolic substitution rules of binary addition can be parallelly implement in the optical logic system. The optical logic system has the advantages of fewer optical hardwares, lower loss of optical power and simple architecture.

本文发表在《光学学报》, 第 12 期, 1989 年

## 新奇轮廓映射方法

### Novel Contour-Mapping Methods

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本文介绍了三种相位物体轮廓映射的光学方法。这三种方法是基于部分相干衍射效应, 它们分别是联合 Talbot 效应, 逻辑操作的莫尔现象和傅里叶滤波。

Three optical methods for contour-mapping of phase objects are introduced. They are based on the partially coherent diffraction effect, the joint Talbot effect and the logic operated Moire phenomenon, and the Fourier filtering.

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上海光学精密机械研究所在光致折变晶体应用于  
光学信息处理方面的研究工作

Applications of Photorefractive Crystals to Optical  
Information Processing at SIOFM

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上海光学精密机械研究所光学信息处理研究小组近几年来在光致折变晶体的非线性性质研究及其在光学信息处理的应用研究方面取得了一些成果。本文主要介绍了一些我们认为其中颇为重要的研究成果: 如 SBN:Ce 晶体中双光束耦合的新结果, 空间光调制的一些新方法, 全息关联存储和空间滤波。

Optical information processing research group at shanghai Institute of Optics and Fine Mechanics(SIOFM) was engaged in recent years in the research on nonlinear properties of photorefractive crystals and their applications in optical information processing and has achieved some results in this field. we report in this paper a few major results which are esteemed rather important in our opinion. They are some new results of beam coupling in SBN: Ce crystals, and some new methods of spatial light modulation, associative holographic memory and spatial filtering.

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光栅编码多通道光致折变非相干光到相干光转换  
Grating-Encoded Multichannel Photorefractive  
Incoherent-to-Coherent Optical Conversion

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本文报导了一种基于 SBN:Ce 晶体光致折变效应的动态多通道非相干光至相干光的转换器。非相干光照明的一系列光栅编码输入像投射到晶体产生相位光栅, 相干光同时照明即读出像。给出了简单理论分析和实验。

A dynamic multichannel incoherent-to-coherent optical converter based on the photorefractive effect of SBN:Ce is described. A number of grating-encoded input images, illuminated by incoherent light, are projected onto the crystal to yield photoinduced phase gratings. Coherent positive replicas of these images are simultaneously reconstructed by a

coherent read beam. A simple theoretical description of this converter and corresponding experimental results are presented.

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### 形态学操作在符号替换和 Hough 变换中的应用

#### Morphological Operations for Symbolic Substitution and Hough Transform

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基于数学形态学, 我们提出了一种可实现符号替换和 Hough 变换的光电系统的结构及算法。实验结果和数值模拟很好地吻合。

We propose, based on mathematical morphology, the architectures to perform symbolic substitution and Hough transform in an opto-electronics system. Experimental results are demonstrated to accord well with their digital simulations.

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### InP / InGaAsP EMBH CCTS 双稳激光器的设计与制备

#### Design and Fabrication on InP / InGaAsP

#### EMBH CCTS Bistable Lasers

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设计并采用二次液相外延研制成功一种腐蚀台条掩埋异质结(EMBH)1.3 $\mu\text{m}$  InP / InGaAsP 双区共腔(CCTS)双稳激光器。InGaAsP 有源区处于腐蚀形成的窄台条之内、被掩埋在宽禁带、低折射率的 InP 层中。有源区宽度  $W$  和厚度  $d$  分别设计成  $W < 2\mu\text{m}$ 、 $d < 0.2\mu\text{m}$ 、以实现低阈值和基横模工作。在有源层两侧设置了 pnpn 闸流管式电流阻挡结构, 并通过对外延工艺特别是二次外延工艺的严格控制, 使有源区相对于闸流管 p 型基区的位置适当, 并使有源区与 p 型基区的界面晶体质量良好, 以便最大限度地减小对受激复合无贡献的无效电流。此外, 对 p 型 InP 上限制层的浓度、厚度等也做了适当设计、以提供两个增益区之间良好电学隔离。

InP / InGaAsP EMBH(Etched Mesa Buried Heterostructure) CCTS (Common-Cavi-



ty Two-Sections) bistable lasers with an emission Wavelength at  $1.3\mu\text{m}$  have been designed and fabricated by two step LPE. InGaAsP active layer was located under the mesa and embedded completely in InP. The width  $W$  and thickness  $d$  of the active layer were designed to be  $W < 2\mu\text{m}$  and  $d < 0.2\mu\text{m}$ , respectively in order to realize low threshold and fundamental transverse mode operation. The pnpn thyatron structure was formed on both sides of the active region. A proper position of the active layer relative to the p base of the thyatron and a good crystal quality of the interface between the active and p base have been realized by controlling the 1st, especially the 2nd LPE procedure so as to reduce the useless current to a minimum. In addition, the concentration and thickness of the p-InP confining layer were designed also in order to provide good electrical insulation between the gain regions.

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### 利用 $\text{BaTiO}_3$ 晶体中自泵浦位相共轭的实时边缘增强

#### Real-Time Edge-Enhancement

#### Using Self-Pumped Phase Conjugation in $\text{BaTiO}_3$

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首次从理论上研究了利用光折变晶体自泵浦位相共轭产生图像边缘增强的机理, 给出了实现图像边缘增强的条件, 并利用  $\text{BaTiO}_3$  晶体的自泵浦位相共轭实现了实时边缘增强。实验中分别测量了  $\text{BaTiO}_3$  晶体自泵浦位相共轭的位相共轭反射率对入射角度和入射位置的依赖关系。实验中实现了二维图像的完全边缘增强和部分边缘增强。这种实现边缘增强的方法具有装置简单、防震性能好等特点, 其在光学神经网络的应用中提高了图像处理功能。

Real-time edge-enhancement of image using self-pumped phase conjugate mirror with  $\text{BaTiO}_3$  crystal is studied for the first time. The dependence of the phase conjugate reflectivity of selfpumped phase conjugator in  $\text{BaTiO}_3$  crystal on incident angle and incident position is measured respectively. The experiment results of the total edge-enhancement image and the partial edge-enhancement image are presented. The device exhibits the characteristic of simplicity and antivibration etc. and can be used in the system of the optical neural network to raise the function of image processing.

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## 利用渥拉斯顿棱镜实现光学全混洗

### Optical Perfect Shuffle Using Wollaston Prisms

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本文首次提出并完成了采用渥拉斯顿双折射棱镜实现两维全混洗的实验,与目前实现全混洗的各种方法相比,这种装置克服了像的倾斜,具有成像质量好、光能利用率高的优点。用这种全混洗装置可以方便地级联构成全混洗网络,它对光计算机的总线结构研究及动态光互联研究有特别重要的意义。

A 2-D optical perfect shuffle is presented and demonstrated in a imaging system which uses Wollaston prisms. As comparing to other techniques as so far to implement perfect shuffle, this kind of 2-D PS system eliminates the tilt of output images, and, therefore the PS image quality is improved. Meanwhile it has a high light efficiency. This PS system is, therefore, easily used for cascading of the PS network.

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## 利用光折晶体 BSO 实现双位相共轭镜

### Double Phase-Conjugate Mirror

### Using Photorefractive BSO Crystal

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本文给出一利用光折变晶体 BSO 中透射型光栅机制同时产生二位相共轭波的双位相共轭镜 (DPCM),报导了这种 DPCM 的实现并从理论上分析了其特性。利用此 DPCM 装置同时成功地消除了二入射信号光波的位相畸变,并实现了二输入图像的和与差运算。

A double phase-conjugate mirror (DPCM), which through a transmission grating mechanism phase conjugates two input beams impinging upon opposite side of a photorefractive crystal BSO simultaneously, is shown here. We report on the successful operation of the DPCM and analyze its properties theoretically. Two optical waves distorted as two input signal waves are corrected simultaneously. Using the DPCM device we also realize addition and subtraction of the two input images.

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在 KNSBN、Pr:KNSBN 和 Cu:SBN 晶体中的光学位相共轲  
Optical Phase Conjugation in KNSBN Fe-Doped  
KNSBN and Cu-Doped SBN Crystal

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本文给出了 KNSBN 系列光折晶体中简并四波混频的理论和实验结果, 分别测量了纯 KNSBN 晶体和掺 Pr 的 KNSBN 晶体中瞬态和稳态位相共轲反射率对空间夹角的依赖关系。首次 KNSBN 系列光折变晶体在施加外电场作用下光折变效应显著增强。实验测得纯 KNSBN 晶体中位相共轲反射率对电场的依赖性。在外电场  $E_0 = 5\text{kV/cm}$  时, 瞬态位相共轲反射率可达 260%, 稳态位相共轲反射率可达 122%。比较发现, 作为一种具有新掺杂的 Pr: KNSBN 晶体的响应速度提高了三倍。实验中测量了 Cu: SBN 晶体的光栅形成时间和位相共轲反射率对入射光强的关系曲线。

Theoretical and experimental results are presented for degenerate four-wave mixing in photorefractive KNSBN crystal. The angular dependence of transient-state and steady-state phase-conjugate reflectivities in undoped and Pr-doped KNSBN have been measured respectively. Applied field dependence of phase-conjugate reflectivity in undoped KNSBN shows that transient-state exceeds 260% and steady-state can reach 122% at applied field  $E_0 = 5\text{kV/cm}$ . By comparison, Pr as a new impurity to provide a variety trapping centers in KNSBN crystals makes the response time about 3 times less. The probe intensity dependence of the response times and the steady phase-conjugate reflectivity in degenerate four-wave mixing with in Cu-doped SBN is given.

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利用光折晶体 KNSBN 和液晶电光开关实现实时关联存储  
Real-Time Associative Memory with Photorefractive  
KNSBN and Liquid Crystal Optical Switches

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本文给出一种利用光折变晶体 KNSBN:Co 作为记忆元件, 液晶电光取阈器的全息关联存储器。实验结果表明, 此系统具有实时多重图像存储和联想输出能力。

We present a real-time holographic associative memory implemented with

photorefractive KNSBN: Co crystal as memory element and liquid crystal electrooptical switches as effective thresholding device. The experimental results show that the system has real-time multiple-image storage and recall function.

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## 实时全息光学存储

### Real-time Holographic Optical Storage

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本文首次测量了具有新掺杂的光折变晶体 Pr:LiNbO<sub>3</sub>、Ce:Fe:LiNbO<sub>3</sub> 的吸收频谱、衍射效率、灵敏度及光擦除特性等。并且展示了一个模拟 HOPFIELD 神经网络模型的实时全息联想系统。此系统用光折变晶体 Ce:Fe:LiNbO<sub>3</sub> 作为记忆元件, 用光折晶体 Fe:LiNbO<sub>3</sub> 进行放大并提供反馈阈值响应。实验中, 利用此系统用部分图像进行寻址, 得到完整图像的输出。

In this paper we report the measurements of the optical absorption spectrum, diffraction efficiency, recording sensitivity, erasure behavior in the poled single crystal LiNbO<sub>3</sub> with Pr and with Ce and Fe as new impurities respectively. We show associative holographic analog to the Hopfield network model in algorithm and present a real-time parallel optical associative memory system implemented with a Ce: Fe: LiNbO<sub>3</sub> crystal as recording medium and a Fe: LiNbO<sub>3</sub> crystal amplifier to provide feedback, thresholding and gain. In our experiment, the retrieval of complete image when only a partial image addresses the system is demonstrated.

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## 利用 Cu:SBN 晶体的外环腔自泵浦位相共轭

### Self-Pumped Conjugate Mirror with External Ring Cavity in Cu: SBN Crystal

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利用具有新杂质能级的掺铜 SBN 晶体获得具有高位相共轭反射率的外环腔自泵浦位

相共轭镜。实验表明,Cu: SBN 晶体具有可与 BaTiO<sub>3</sub> 晶体相比的光折变性能。实验获得高达 50% 的位相共轭反射率。研究了总入射光强对位相共轭和速度的影响, 给出了位相共轭反射率的角度响应曲线及入射光强的依赖关系曲线, 利用此自泵浦位相共轭反射镜消除了光波的位相畸变。

Self-pumped phase conjugation mirror with external ring cavity in Cu-doped SBN crystal is obtained. Experimental results demonstrate that Cu: SBN possesses the photorefractive features which are comparable to BaTiO<sub>3</sub> crystal. The phase conjugate reflectivity of the devices can reach 50%. The effects of the total incident optical intensity on the phase conjugate optical intensity and response speed of the self-pumped phase conjugate mirror are presented. The experimental curves of phase conjugate reflectivity versus the external coupling angle and incident optical intensity are shown. A light wave with aberration caused by a distorter is corrected by the device.

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### 利用 Fe: LiNbO<sub>3</sub> 晶体实现相干光波耦合放大和弱图像增强

#### The Coupling Amplification of Coherent Optical Wave and

#### Enhancement of Weak Images with Fe: LiNbO<sub>3</sub> Crystal

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本文从耦合波理论出发推导出光折晶体中多束光波耦合过程中由于能量转移而获得的增益放大率的解析式, 并与利用 Fe: LiNbO<sub>3</sub> 晶体的双光束放大实验结果进行了比较。利用三束光波耦合能量转移效应实现了两弱图像的增强。

This paper presents the formation of amplification caused by energy transfer in multiple optical waves coupling process in photorefractive crystal, and makes a comparison between theoretical results and experimental results. Using the effect of energy transfer in three light coupling, two weak images are enhanced.

本文发表在《哈尔滨工业大学学报》, 第 4 期, 1990 年

### 用互补向量修正阈值的光电混合联想存储器模型

#### Optical Electric Hybrid Associative Memory Model

#### with Threshold Modification Using Complementary Vector

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本文提出了一种在联想存储中评价向量间相似程度的新判据。通过改进输入、输出信息的编码方式改善了联想读出的准确率。完成了一种采用互补向量修正阈值的光电混合联想存储器模型的实验研究。该模型可以控制读出向量的精度,能够消除向量的误读。

A new kind of criterion for evaluating the degree of the similarity between two vectors in associative memorizing is proposed. By choosing the coding of input and output information, the performance of associative memorizing is improved. An experiment about the optical electric hybrid associative memory model with threshold modification using complementary vectors is designed and implemented. This model is capable of controlling the accuracy to retrieve vector and eliminating the possibility to read out erroneously.

本文发表在《光学学报》,第9卷,第7期,1989年

### 光折晶体 Fe: LiNbO<sub>3</sub> 中的光致散射效应

#### Light-Induced Scattering in Fe-Doped Photorefractive LiNbO<sub>3</sub> Crystals

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(\* 哈尔滨工业大学、\*\* 大连铁道学院)

从耦合波理论出发对严重影响光折晶体中全息光栅记录的光致散射现象进行了理论分析,给出了平面波经过光折变晶体后透射光强的解析表达式,并首次得到随散射角和波长等因素变化的散射光波强度解析式。利用 Fe: LiNbO<sub>3</sub> 晶体以氩离子激光为光源研究了光致散射效应,得到了透射光强度随时间变化的动态曲线,以及与理论一致的散射光强随散射角变化的实验曲线。实验中还观察到表面复合效应,并提供了简便地消除此效应的方法。

The light-induced scattering effect affecting severely holographic grating recorded in photorefractive crystal is analyzed by using the coupled-wave theory. Using Fe: LiNbO<sub>3</sub> crystal the experimental results are demonstrated.

本文发表在《中国激光》,第16卷,第9期,1989年

### 近邻局域互联神经网络

## Near Neighboring Neurons Interconnected Neural Network

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本文根据人脑的生理结构模型特点提出了近邻局域互联神经网络模型, 计算机数字模拟表明这种局域互联神经网络在不显著地降低神经网络收敛性的情况下, 有效地减少了互联的个数。特别是当这个神经网络模型应用在存储密度不是很大的情况时, 有相当好的收敛性。这种近邻局域互联神经网络模型的提出, 对于解决实际构成最佳规模的神经网络有很重要的意义。

A neural network with interconnection of near neighbouring neurons is presented according to the property of physiological structure model of the human brain. Computer numerical simulation shows that the number of interconnection is effectively reduced, but the convergence property can be achieved while the storage density of this model is not too high. The presentation of this kind of near neighboring neurons interconnected is useful for the construction of neural network with optimal interconnection scale.

本文发表在 Optics Communication, Vol.76, No. 3-4, 1990

## 利用光折变晶体和液晶电光开关实现实时联想存储

### Performance of Real Time Associative Memory Using a Photorefractive and Liquid Crystal Electrooptic Switches

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本文首次给出了一种用光折变晶体 KNSBN:Co 作为存储元件, 用液晶电光开关阵列提供反射式阈值装置的实时全息关联存储器。实验中实现了两幅图像的存储和再现, 并证明此系统具有实时多重图像存储和再现功能。本文提出了一种具有动态阈值装置的关联存储器, 这种存储器是由一干涉滤光片双稳装置和一用光敏电阻器件构成的反馈控制网络组成。这种关联存储系统把光学的并行处理功能和电子网络的灵活性结合起来, 是一种实用的关联存储系统, 具有阈值低并可调节的特点。

In this paper, we present a new real time parallel holographic associative memory system and its results. In our system, a KNSBN: Co crystal acts as the memory element, and a liquid crystal electrooptic switch (LES) array is used as the reflective thresholding device to provide binary thresholding response. We propose an associative memory with dynamic threshold level device made of a bistable interference filter and feedback control networks

that have light sensitive resistors. Our system combines the parallel processing capability of optics and the flexibility of an electronic network, and is more practical its threshold level is much lower and can be adjusted.

本文发表在 Applied Optics, Vol.29, No.9, 1990

### 光折变二波混频中的位相研究和光波畸变的消除 Observation of Optical Wave Phase and Wave-Front Correction in Photorefractive Two-Wave Mixing

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首次观察到光折变晶体  $\text{Bi}_{12}\text{GeO}_{20}$  中耦合光波位相与光强之间的耦合效应。从理论上研究了在光折变晶体  $\text{Bi}_{12}\text{GeO}_{20}$  二波耦合中耦合光波的位相变化对于外电场、光束比、光栅空间频率的依赖性,并与实验结果进行了比较。实现一种消除光波位相畸变的新方法。

The coupling effect between coupled optical wave phase and intensity is observed in photorefractive  $\text{Bi}_{12}\text{GeO}_{20}$  crystal. The dependence of coupled wave phase variation on applied field, light beams ratio and grating spacing in two-wave mixing with  $\text{Bi}_{12}\text{GeO}_{20}$  crystal is studied and the comparison between the theoretical results and experimental results is made. A way to correct wavefront-distortion is demonstrated.

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### 用于光开关和光计算的多层量子阱 Multiple Quantum Well Structure in Optical Switching and Optical Computing

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本文讨论了超晶格材料(多层量子阱结构)在光开关和光计算中应用的优越性。从其特殊的结构出发,讨论了其非线性机制以及比体单晶优越的特点。给出了多层量子阱器件可能用于光计算的集成器件方案。

This paper discusses the advantages of superlattice semiconductor materials (Multiple Quantum Well Structure) in optical switching and optical computing. From the special



structure of MQW, their nonlinear mechanism and advantages over that of pure crystals are discussed. This paper also proposes possible designation of integrated devices used in optical computing.

本文发表在《哈尔滨工业大学学报》, 第1期, 1990年

## 平面微透镜阵列的多重图像变换及应用

### The Multiple Image Transformation of Planar Microlens and Its Applications

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在光学信息处理和光计算领域, 常常需要进行图像的多重成像和变换, 目前采用的器件有微孔列阵、二维光栅、光纤面板、全息器件等, 均因各种缺点而未如人意。自聚焦复合透镜面列阵, 由于其制作特点, 使得排列均匀, 光性一致、集成度高、透镜元体积小、数值孔径大、分辨率高, 使它在光纤通信、光计算及机器人视觉和信息科学中具有重要应用前景。文中提出一种采用平面微透镜面列阵进行图像多重变换和处理的系统, 并获得多重成像的照片。

In the fields of optical information processing and optical computing, the multiple image transformations are often needed. Micro hole array, two dimension grids, fiber plate, holographic elements are the devices used in the field at the present, but they are not satisfied because of various disadvantages. Microlens array, arranged in a good order, has large scale integration, and the lens lit is small in size, large in numerical aperture, high in resolution. All of this makes it a good future in fiber communications, optical computing, robot vision and information science. The paper suggested a system for multiple image transformation and processing.

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## 自聚焦平面微透镜阵列的折射率分布与工艺条件

### The Index Distribution and Fabricating Condition of Gradient Index Planar Microlens Array

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采用我们在以前文章中获得的平面微透镜制作工艺扩散方程的解析解, 由计算机编程运算画出了等折射率分布曲线, 证明了解析解的物理正确性。由我们的工艺所得相关参数, 根据扩散方程的解, 我们求得了相应的扩散系数  $D = 6.53 \times 10^{-5} \text{mm}^2 / \text{hr}$ 。这样, 我们可以结合理论和实际工艺, 使得折射率分布尽可能接近理想情形。

Using the analytic solutions of ion diffusions, obtained by authors before, the equal index contours by computer programming were plotted. This shows that the analytic solutions are correct. From the experiment data and the solutions of diffusion equations, the diffusion coefficient is obtained  $D = 6.53 \times 10^{-5} \text{mm}^2 / \text{hr}$ . So, we can make the index distribution close into the ideal profile by combining the theory with the practical experiment.

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### 自聚焦平面微透镜成像特性分析

#### The Imaging Property of Self-Focusing Planar Microlens Array

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利用普通光线方程对自聚焦复合透镜面列阵的成像光线进行了分析; 得出了透镜列阵的成像矩阵, 给出了自聚焦复合透镜面列阵高斯参量的计算公式; 并与实验结果进行了比较, 得到了满意的结果。

By using ray equation, the imaging ray of selffocusing planar microlens array is analysed, the ray trajectory and the imaging matrix is obtained, the formula of Gaussian parameter is given, and showing good agreement to the experiment results.

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### 掺半导体玻璃 (SDG) 的光学非线性

#### Optical Nonlinearity of Semiconductor Doped Glass(SDG)

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通过吸收和发射光谱的测量, 研究了  $\text{CdS}_x\text{Se}_{1-x}$  玻璃的量子尺寸效应, 用导波测量方法确定了该种材料非线性折射率变化的饱和值; 首次研制成功了开关速率为 31PS, 阈值功率密度  $47\text{kW} / \text{cm}^2$  的内 F—P 腔结构的  $\text{CdS}_x\text{Se}_{1-x}$  玻璃光学双稳阵列器件。内 F—P 腔

设计是使  $\text{CdS}_x\text{Se}_{1-x}$  玻璃光学双稳迈向小型化和集成化的重要一步。如果把激光束斑尺寸限制在  $10\mu\text{m} \times 10\mu\text{m}$  范围内, 并与自聚焦透镜结合, 则每个阵列元的开关能耗仅 3PJ, 这一超快速低能耗双稳阵列, 有可能作为未来全光数字计算系统中的关键部件而得到应用。

Quantum size effects in  $\text{CdS}_x\text{Se}_{1-x}$  doped glass are studied by measurement of the absorption and emission spectra. The saturation value of the nonlinear refractive index change is determined by guided wave measuring method and the optical bistability array device with internal F-P cavity structure (switching rate 31PS, threshold power density  $47\text{kW}/\text{cm}^2$ ) is successfully realized for the first time. The design of internal F-P cavity structure is taken as an important step in developing small and integrated optical bistability device in  $\text{CdS}_x\text{Se}_{1-x}$  doped glasses. If laser spot focused on the sample is limited to  $10\mu\text{m} \times 10\mu\text{m}$  in size and self-converging lens is adopted, the switching energy loss of each element of array is only 3PJ. This device of ultrafast and lower energy loss bistability array will be expected to be used as a crucial component in the system of all-optic digital computing for the future.

本文发表在“1990 中苏双边科技交流邀请报告”

### 无像差波导短程透镜的研制

#### Study of Waveguide Geodesic Lenses with Aberration-Free

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本文报导我们对  $\text{LiNbO}_3$  无像差波导短程透镜的初步研究。

样品为  $40 \times 20 \times 3\text{mm}$  的 Y-切割  $\text{LiNbO}_3$  晶片, 凹面直径为 8mm, 通光孔径为 6mm, 凹面边缘有圆弧形光滑过渡区。凹面形状采用最优化程序在 L-470 机上算得。采用单点金刚石超精加工法加工凹面, 经抛光后, 用 Ti 扩散工艺形成光波导短程透镜, 经实验测量, 凹面深度为 0.94mm; 在通光孔径范围内, 焦距 (19mm) 没有变化 (没有球差), 透镜损耗很小, 能满足集成光学频谱分析器的要求。

In this letter, our study for aberration-free  $\text{LiNbO}_3$  waveguide lenses is reported.

The sample is the y-cut  $\text{LiNbO}_3$  plate of  $40 \times 20 \times 3\text{mm}$ . The lens aperture and effective aperture are 8mm and 6mm, respectively, the lens has rounding edges. The single point diamond turning was employed to grind the lens shape. After machine-polishing, the waveguide geodesic lenses were formed by Ti diffusing technology. The experiment measuring shows that the lens depth is 0.94mm, the focal length is constant in the range of effective aperture, and the lens insertion loss is very small ( $< 1\text{dB}$ ). So the requirement of IOSA

can be satisfied.

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### 光学矩阵乘法器的实验研究

#### Experimental Study on Optical Matrix Multiplier

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我们在  $\text{LiNbO}_3$  晶体衬底上制造了一个 IO 声光矩阵乘法器的简单样品, 并观察到 2 矩阵元的模拟乘法和加法运算。器件是由 Ti 扩散平面光波导、波导短程透镜和叉指换能器组成的。

入射在样品一端的 He—Ne 激光束用于输入 B 矩阵元, 在另一端的 CCD 探测器收集衍射光。换能器产生的 SAW 用来输入 A 矩阵元。用声光相互作用实现矩阵乘法操作; 用 CCD 探测器实现加法操作。

We fabricated an IO acousto-optical matrix multiplier on a  $\text{LiNbO}_3$  substrate and observed analog multiplication and addition for 2 matrix element. The device consists of Ti diffusion planar optical waveguide; geodesic lens, and interdigital transducer. A He—Ne laser beam incident at a end of sample used as the input of B matrix elements. The CCD detector collected the diffraction light. Transducer produces the SAW and input the A matrix elements. The multiplied operation was realized through acousto-optical interaction. The additive operation was realized on the CCD detector.

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### 一种制作用于在 VLSI 中光互连的全息光学元件的新方法

#### A New Method of Recording Holographic Elements Applied to Optical Interconnect in VLSI

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本文首次提出用 Wollaston's 棱镜所成的像作为物光记录用于在 VLSI 中光学互连的全息光学元件。由于重叠 Wollaston's 棱镜成像的偏振特性, 制作 HOE 的物光束不发生干涉, 在 HOE 中没有内调制效应。因此, 在再现过程中没有高阶像, 信噪比大, 用这种方法和重铬酸明胶作全息记录材料, 我们制作了一系列用于光互连的全息元件, 这些

元件的扇出数分别为  $1 \times 2$ ,  $2 \times 2$ ,  $2 \times 4$ ,  $4 \times 4$  等它们的效率都在 60% 以上。最后指出这种方法不仅对制作用于光互连的全息光学元件非常有效而且对制作分束器, 耦合器等也非常有效。

In this paper, the images formed by cascaded Wollaston's prisms as object beams for recording HOE applied to optical interconnect in VLSI are first proposed. Because of polarization property of the images formed by Wollaston's prism the object beams for constructing HOE do not interfere and there is no intermodulation in HOE. Therefore, there are no higher order images and the SNR is high. Using this method and dichromated gelatin as holographic recording material, we have manufactured a number of HOEs for optical interconnect. The number of fan-out of these HOEs is  $1 \times 2$ ,  $2 \times 2$ ,  $2 \times 4$ ,  $4 \times 4$  ect and the diffraction efficiencies are above 60%.

In conclusion, this method for manufacturing HOEs for optical interconnect is very effective. And this method is also useful for making HOEs for beam splitter and coupler ect.

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### 高效率多重像全息光学元件

#### Efficient Multiple-image Holographic Optical Element

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本文描述了一种集中计算机全息图多重像和体全息图高效率等优点的全息光学元件, 给出了具有改善效率和信噪比的全息元件的实验结果, 讨论了这种元件用于光学互连的可能性。

An efficient holographic optical element that combines the beam multiplexing properties of binary-phase computer-generated holograms with the efficiency of volume holograms formed in dichromated gelatin is described. Experimental results for an element that improves both the efficiency and the signal-to-noise ratio of a computer-generated hologram are presented. The possibility of using this element as an optical interconnect is discussed.

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### 关于几个主要实验参量的讨论

## Some Experimental Parameters in Holographic Interconnect Elements

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首先, 我们研究了主光栅折射率调制, 记录材料的最大折射率调制和调制比之间的关系, 讨论了最大折射率调制, 光束比和光束数目对多束光互连元件效率的影响, 给出了相应的关系曲线。

At first, we go into relation among the main grating refractive modulation, the maximum refractive modulation of recording material and the ratio of refractive modulation amplitudes. Effects of the maximum refractive modulation, the beam ratio and the number upon the efficiency of multiple-beam interconnect elements. The appropriate relation curves are given.

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## 多光束全息互连元件效率的理论分析

### Theoretical Analysis on the Efficiency of Multiple-Beam Holographic Interconnect Element

陈西园 耿完桢

(哈尔滨工业大学)

本文从理论上分析了多光束互连元件衍射效率问题, 并将这一问题进行简化, 给出同时曝光和顺序曝光衍射效率的分析表达式, 以及衍射效率与实验参量的关系。

In this paper, the efficiency of multiple-beam interconnect element is analysed theoretically and the problem is simplified suitably. And the analytical approximate expressions for the elements recorded simultaneously and sequentially by multiple beams are given. The relation between diffraction efficiency and some experimental parameters is displayed.

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## 七、新型材料、器件和工艺技术 Advanced Materials, Devices and Processing Techniques

### 双区半导体激光器的稳定性理论

#### A Theory on Stability of Double-Section Semiconductor Lasers

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在考虑两区直接光耦合的基础上,建立了双区半导体激光器的稳定性理论,给出了产生自脉动和双稳态的必要条件和充分条件的公式,并对已经报道过的一些实验结果作出了理论解释。

Taking into account the direct optical coupling between two sections, a theory on stability of double-section semiconductor lasers is established. Formulas showing necessary and full conditions for the occurrence of self-pulsation and bistability are obtained. Also, several experimental results previously published are explained theoretically herewith.

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### 准分子激光诱导湿刻 GaAs

#### Excimer Laser Induced Aqueous Etching GaAs

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本文报告了在  $\text{HNO}_3$  水溶液中,准分子激光诱导湿刻 n 型和半绝缘 (SI) 型 GaAs 过程,并获得了光滑垂直的刻蚀结果。n 型和 SI 型 GaAs 刻蚀速率的差异是由于两种材料表面能带弯曲不同。在高激光功率区域,刻蚀速率的增加受到 GaAs 表面反应生成物脱附速率的限制,因此两种材料刻蚀速率差别很小。在低激光功率区域,没有这种限制,刻蚀速率差异较大。

This paper reports on excimer laser induced wet etching n type and semiinsulating (SI) GaAs process in the  $\text{HNO}_3$  aqueous solution and obtaining very smooth, vertical features. The etching rate difference between n type and SI type GaAs is due to the band bending in

the semiconductors. For high laser power density, etching rate increases limited by rate of reaction products desorption at GaAs surface. Thereby, etching rate difference between n and SI type GaAs is small. For low laser power density, etching rate difference only depends on the band bending, so it is big.

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### 锁相激光列阵自成像孔径装填的装填因子研究

#### Study of Fill Factor in Self-Imaging Aperture Filling of Phase-Locked Arrays

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锁相激光列阵可以通过对它们的自成像的位相补偿来实现孔径装填。本文从理论上研究了二维矩形孔径列阵和圆孔径列阵的装填因子，分析讨论了孔径数目，衍射距离和孔径占空比对装填因子的影响。

Phase-locked laser arrays can be aperture-filled by the phase compensation of their fractional self-images. In this paper, theoretical analyses are given on 2-D arrays with rectangular or circular aperture emitters. The effects of the number of array elements, the diffraction distance and the array opening ratio on the fill factor are discussed.

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### 锁相激光列阵的自成像补偿法孔径装填

#### Aperture Filling of a Phase-Locked Laser Array by Phase Correction with Self-Imaging

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锁相激光列阵产生多旁瓣的远场衍射花斑。本文提出了用列阵的 Talbot 衍射自成像转化为等幅等位相分布的概念，并用相位补偿使旁瓣能量转移到光主瓣，实现了孔径装填。

A phase-locked laser array generates a far-field diffraction speckle pattern consisting



of many side lobes; in this paper we propose to use the concept of Talbot diffraction self-imaging to transform the array into an equal amplitude phase distribution. We then use phase correction to shift the side lobe energy to the main bright lobe, thereby producing aperture filling.

本文发表在《中国激光》, Chin. J. Lasers, Vol. 16, No. 1, p.37 1989, 及 Chinese Phys., Vol. 9, No. 3, p. 810, 1989

### **Lau 共振腔和列阵激光锁相**

#### **Lau Cavity and Phase Locking of Laser Arrays**

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本文提出了 Lau 共振腔的概念, 它是在 Lau 成像条件下的带有相位补偿板的自成像腔。Lau 共振腔同时利用了 Talbot 效应和 Lau 效应来锁相一维或二维激光二极管列阵, 并能取得单一主瓣输出。着重分析了相干受激辐射时的自洽条件和非相干自发辐射时的自成像条件。

The Lau cavity is the self-imaging cavity with a phase corrector under the Lau reimag-ing condition. I propose the use of the Lau cavity to utilize both the Talbot and the Lau ef-fects for phase locking one-dimensional and two-dimensional diode-laser arrays into a single-lobe coherent beam. Analyses on the self-reproducing of a coherent lasing field and the reimaging of the initial incoherent radiation are given.

本文发表在 Opt. Lett., Vol. 14, No. 23, p.1312, 1989

### **任意平面物体的取向和角速度的相关检测**

#### **Correlation Detection of an Arbitrary Planar Object's**

#### **Orientation and Angular Speed**

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本文提出了用光学偏振编码和圆谐函数展开法进行任意平面物体的取向及角速度的测量方法。

A method of detecting an arbitrary planar object's orientation and angular speed by

means of optical polarization encoding and circular harmonic expansion is proposed.

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**GaAs-GaAlAs 质子轰击条型激光器与光纤耦合效率的研究**  
**Studies on The Coupling Efficiency Between GaAs-GaAlAs Laser with**  
**Proton**

**Bombardment Stripe Structure And Optical Fiber**

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本文详细介绍半导体激光器与带有锥半球透镜的光纤间的有效耦合。实验结果表明,采用在光纤一端熔制成锥半球透镜的耦合方法,具有效率高、容差大、反射光影响小、重复性好、封装结构简单等特点。光纤的锥半球透镜是利用电弧放电制成。采用该方法可重复制做出不同形状的锥半球透镜。单模光纤锥半球透镜最佳形状为:半球曲率半径为  $15\mu\text{m}$ , 锥长  $500\mu\text{m}$ 。单模光纤最大耦合效率达到 60%。多模光纤锥半球透镜最佳形状为,半球曲率半径为  $17.5\mu\text{m}$ , 锥长  $500\mu\text{m}$ 。最大耦合效率达到 95%。

This paper discusses the coupling efficiency between semiconductor laser and optical fiber. Experimental results indicate that the coupling by means of the optical fiber with melted tapered hemispherical lens has many advantages, such as: high efficiency, large tolerances, less reflection effect, good reproducibility and simple arrangement etc. The tapered hemispherical lens of different shape have been fabricated.

Optimum shape of single mode fiber tapered hemispherical lens is: hemispherical curvature radius  $15\mu\text{m}$ , taper length  $500\mu\text{m}$ . Maximum coupling efficiency of 60% is achieved. Optimum shape of multimode fiber tapered hemispherical lens is: hemispherical curvature radius  $17.5\mu\text{m}$ , taper length  $500\mu\text{m}$ . Maximum coupling efficiency of 95% is achieved.

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**大功率衍射极限 GaAs-GaAlAs 锁相激光器列阵**  
**High Power Diffraction Limited Phase-Locked GaAs-GaAlAs**  
**Semiconductor Laser Array**

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利用液相外延、光刻技术、湿法腐蚀及质子轰击等技术研制成大功率衍射极限 GaAs-GaAlAs 锁相激光器阵列。改变激光器条宽而激光器间距不变, 获得特定的增益导引阵列。此阵列由六只激光器组成。其输出光功率在  $2.7I_{th}$  时达  $300\text{mW}/\text{面}$ , 单纵模、CW 运行, 远场分布为单瓣, 其 FWHM 为  $1.9^\circ$ 。

High power diffraction limited GaAs-GaAlAs phase-locked semiconductor laser arrays are developed and fabricated by LPE technique, standard photolithographic technique, wet etching and proton-bombardment. The tailored gain-guided arrays are carried out by varying width of stripe of laser while the spacings between lasers keep constant. This array consists of six lasers. Its optical output power per facet is  $300\text{mW}$  at  $2.7I_{th}$ , single mode CW operation, single-lobe far field pattern with FWHM  $1.9^\circ$ .

本文发表在 90 年汉城“国际第四届亚太地区物理学术会议”, 及 Fiber & Integrated Optics, Vol.9, No.4, 1990

### 激光二极管锁相阵列模式和远场分布的研究 The Study of the Mode and Far-Field Pattern of Diode Laser Phased Arrays

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在许多应用中都追求单模、远场分布单瓣、衍射极限的激光二极管锁相阵列。根据耦合模理论分析, 设计并制造了三种激光二极管锁相阵列: 条宽相等和间距相等的均匀阵列; 条宽按“V”字形调制和间距相等的对称阵列; 条宽由左至右逐步增宽和间距相等的非对称阵列。

此三种阵列的特性表明非对称阵列比之均匀阵列和对称阵列具有非常大的选超阶模特性, 并且导至单瓣远场分布。

用液相外延和微加工技术研制成 GaAs-GaAlAs 非对称调制阵列。此非对称阵列由六只激光器组成。其条宽由  $3\mu\text{m}$ ,  $4\mu\text{m}$ ,  $5\mu\text{m}$  变至  $8\mu\text{m}$ , 而其间距保持不变为  $5\mu\text{m}$ , 其输出光功率为  $300\text{mW}$ , 单模, 远场分布单瓣, 衍射极限 FWHM 为  $1.9^\circ$ 。

Diode laser phased arrays of single mode, single lobe and diffraction-limited far-field pattern are pursued for many applications. According to coupled mode analysis, three type

diode laser phased arrays have been designed and fabricated: the uniform arrays with equal wide channels and equal spacings; the inverted “V” chirped arrays with varying wide channels and equal spacings; the asymmetrical chirped arrays with increasing channel-width from left to right and equal spacings.

The properties of these three types arrays show that the asymmetrical chirped arrays allow for a very large discrimination against the higher order supermodes in contrast to the uniform structure and symmetrical structure and would result in a deflection of main lobe.

GaAs-GaAlAs asymmetrical chirped arrays are manufactured by LPE and microtechnology. The asymmetrical arrays consist of six lasers. The width of channel is varying from  $3\mu\text{m}$ ,  $4\mu\text{m}$ ,  $5\mu\text{m}$ ... to  $8\mu\text{m}$  and the spacings between lasers keep constant  $5\mu\text{m}$ . This array has given 300mW optical output, single mode, single lobe far-field pattern, diffraction limited FWHM  $1.9^\circ$ .

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### InP / InGaAsP[011]与 $[01\bar{1}]$ 晶向的简便判别

#### Simple Discrimination between Orientations $[011]$ and $[01\bar{1}]$ of InP / InGaAsP

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准确地区别两组互相垂直的晶向 $[011]$ 和 $[01\bar{1}]$ ，在各种掩埋异质结 (BH) 激光器、脊形波导激光器以及光双稳激光器的制备中具有重要意义。文献中通常采用腐蚀的方法进行判别，虽然准确，但既费时间又费材料。

我们在 InP / InGaAsP 一次及二次液相外延片表面形貌研究中，发现了一种与晶向密切相关的生长不完美性，其形状或呈椭圆，或呈矩形。与腐蚀法类似，椭圆的短轴或矩形的短边方向即 $[011]$ 晶向。

文中将探讨这种特殊形貌的形成机制，并介绍判别中的应注意事项。

To distinguish exactly  $[011]$  orientation from  $[01\bar{1}]$  is significant in the fabrication of Various InP / InGaAsP buried heterostructure (BH) lasers, ridge waveguide lasers and optical bistable lasers. The chemical etching method used to be employed in literature. Although this method is accurate, it takes a lot of trouble. A kind of special surface morphology with rectangular or elliptical shape has been found on InP / InGaAsP LPE wafers, which is dependent closely on the crystal orientation. Similar to the etching method, the minor axis of the ellipse or short side of the rectangle is along the  $[011]$  direction.

The forming mechanism of the morphology will be discussed and some matters needing attention will be presented in this paper.

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### 硅上 MBE 法生长的 GaAs 材料的电子和光学性质

#### Optical and Electrical Properties of GaAs Layer on Si Substrate

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对不同的 GaAs / Si 样品进行了光荧光，电化学 C-V 及 Hall 测量。2 $\mu\text{m}$  厚的样品的 PL 强度比 1 $\mu\text{m}$  样品强得多，谱峰的半宽度也较小，说明随 GaAs 膜厚的增加 GaAs / Si 膜的质量得到改善。此外，PL 峰与 GaAs 相比向低能方向移动约 10meV，相应膜受到 1.75kbar 的张应力。样品经过 RTA 处理 (850 $^{\circ}\text{C}$ ，6s) 后，PL 强度增加，谱峰向高能方向移动 6meV，表示样品退火后应力减小了。由 Hall 测量得到的 GaAs / Si 膜的电子霍尔迁移率为 1870 $\text{cm}^2/\text{Vs}$ ，电子浓度为  $8.4 \times 10^{16}/\text{cm}^3$ 。这与电化学 C-V 测试结果一致。用该材料已试制出性能优良的 MESFET 器件。

Photoluminescence (PL), electrichemical C-V and Hall measurement have been used to study the optical and electrical properties of GaAs / Si PL intensity of 2 $\mu\text{m}$ -thick sample is much stronger than that of 1 $\mu\text{m}$ -thick sample. It proves that the GaAs / Si quality is improved with increasing thickness of the film. Besides, compared with GaAs / GaAs sample, the peak of PL shows a 10 meV shift to lower energy. And correspondingly the film is subjected to a tensile stress of 1.75kbar in GaAs / Si layer. After treatment by RTA (850 $^{\circ}\text{C}$ ，6s), PL intensity increases, and the peak shifts to high energy with 6 meV. This shows that the stress becomes smaller after annealing. Hall measurement gives a 1870 $\text{cm}^2/\text{Vs}$  mobility with  $8.4 \times 10^{16}/\text{cm}^3$  electron concentration, in agreement with C-V results. GaAs MESFETs with excellent characteristics have been obtained by using these materials.

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### 硅上 GaAs 薄膜的 Raman 光谱研究

#### Raman Spectroscopy Investigation of GaAs Film Grown on Si Substrate

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由于硅和砷化镓之间的晶格失配和热膨胀系数的不同, 使在硅衬底上生长 GaAs 膜十分困难。在 MBE 生长中, 采用两部生长法和超晶格应变层技术 (SLS) 有利于膜质量的改善。我们用 Raman 光谱对不同条件下生长的 GaAs / Si 膜进行了纵向深度分析, 发现在 GaAs-Si 界面全部为压缩应力, 这是晶格失配的结果。而随着膜的生长, 压缩应力逐渐减小。在表面, 用 SLS 技术生长的 GaAs 膜表现为张应力, 而未用 SLS 技术生长的膜仍为压缩应力。张应力起源于硅和砷化镓热膨胀系数的差别。结果说明超晶格应变层 (SLS) 能有效阻挡晶格失配引起的压缩应力, 使膜的质量明显改善。

The mismatch of lattice and thermal expansion coefficient between si and GaAs make it very difficult to grow high quality GaAs on Si substrate. For MBE method, "Two Step" method and strain layer superlattice (SLS) technique have been used to improve the quality of GaAs layer. Raman spectroscopy results show that due to the lattice mismatch, a compressive stress exists in the GaAs layer near the interface for both "Two Step" method and SLS sample. The compressive stress reduces as it is away from the interface. On the surface, SLS sample has tensile stress, in contrast to the compressive stress associate with the "Two Step" sample. Our Results show that SLS buffer can effectively compensate the compressive stress caused by lattice mismatch and improve the quality of grown layer.

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### 电荷 DLTS 方法及其对 MBE 生长硅上砷化镓层深能级的研究

#### Charge DLTS Method and Study on Deep Level in GaAs Layer on Si Substrate

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本文提出并建立了具有漏电补偿功能的电荷 DLTS 方法。该方法具有与电容 DLTS 方法相同的率窗特性, 同时又能直接测量深能级热发射的电荷响应而不必依赖耗尽区厚度的热发射调制, 因此能用于半绝缘材料及耗尽层厚限定 (如 PIN, SOI 结构) 材料中的深能级测量。所建立的测量系统利用微机控制, 可以在一次温度扫描中完成测量过程。利用该系统首次测量了 MBE 生长硅衬底砷化镓材料上 LED 二极管有源区中的深能级密度及位置, 证实了其中高密度深能级的存在。

This thesis advances a new Charge DLTS method that can compensates the leakage current. The method has the same rate-window property as the Capacitance DLTS

method, and it can measure the charge response of the deep level's heat emission and can be independent on the heat emission modulation of the exhausted area's depth. So it can be used for study of special structures, such as SOI,  $P^+IN^+$  and other hetero-structures. The established measurement system is controlled by microcomputer and can complete the whole measure within only once temperature scanning procedure. The system has first measured the deep level's density and position in active areas of GaAs LED devices on Si substrate grown by MBE, and has identified the existence of high density deep level.

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### MBE 生长硅上砷化镓 MESFET

#### MESFETs Fabricated on MBE-Grown GaAs / Si

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用 MBE 法生长的 GaAs / Si 材料制造出 N 沟 GaAs 的 MESFET 器件。7 $\mu$ m 栅长的器件具有跨导 40ms / mm。用 HP-4061 测试了器件的肖特基垒参数, 垒高度为 0.72eV, 理想因子为 1.1。由器件特性分析, 室温电子迁移率和电子的饱和漂移速度分别为 2000cm<sup>2</sup> / Vs 及 0.97 $\times$ 10<sup>7</sup>cm / s。

n-GaAs MESFETs have been fabricated on MBE-grown GaAs / Si substrate. The devices with 7 $\mu$ m gate length show good 1-V characteristics with transconductances of 40 ms / mm. The schottky barrier parameters measured by HP-4061 are 0.72eV for barrier height and n=1.1 for ideal factor. The room temperature electron mobility and saturated velocity are 2000cm<sup>2</sup> / Vs and 0.97 $\times$ 10<sup>7</sup>cm / s respectively.

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### 硅上 AlGaAs / GaAs 单异质结 LED 的研制及特性

#### Fabricated and Characteristics of SHLED of AlGaAs / GaAs on Si

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国内第一只硅上单异质结 AlGaAs / GaAs 面发光 LED 器件已研制成功。材料是用 MBE 法生长的。管芯面积为  $100 \times 100 (\mu\text{m}^2)$ , 有源层厚度为 400nm, 电极采用延伸结构, 以适应将来单片集成的要求。器件的反向电压为 5~10V, 在 10mA 的驱动电流下, 发光功率达  $0.4\mu\text{W}$ 。发光功率与驱动电流呈线性关系。发光谱的峰位波长为 860nm, 光谱半宽度为 37.5nm。

The LEDs of Single-heterojunction AlGaAs / GaAs have been fabricated in the materials of AlGaAs / GaAs on Si grown by MBE in our laboratory. The devices, whose area was  $100\mu\text{m} \times 100\mu\text{m}$  show the breakdown potentials between 5 and 10 voltages. The light output-power which were proportion to driving currents, reached  $0.4\mu\text{W}$  under 10mA, and the wavelength was 860nm, with the peak linewidth 37.5nm.

本文发表在《第六届全国化合物半导体和微波光电器件学术会议论文集》

### Si 上选区分子束外延 GaAs (SAMBE) 及 Si-GaAs 兼容工艺研究 SAMBE GaAs / Si and Studies of Si-GaAs Compatible Technology

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选区分子束外延方法 (SAMBE) 被发展来改善 GaAs / Si 膜的质量。首先在衬底上制作硅 MOS 器件, 用 200nm 的  $\text{Si}_3\text{N}_4$  覆盖其表面以保护在生长 GaAs 层时器件不被损坏。然后用光刻的方法在  $\text{Si}_3\text{N}_4$  膜上开出窗口并用 MBE 法生长 GaAs 膜。测试显示在窗口区生长的 GaAs 的光荧光强度比用普通方法生长的 GaAs / Si 层大。更重要的是我们现在在生长 GaAs 层后, 硅 MOS 器件仍保持原有的特性, 这说明硅和砷化镓的单片集成是可行的。

Select-Area MBE method has been developed to improve the quality of GaAs films on Si. The 200nm-thick  $\text{Si}_3\text{N}_4$  films were covered on the surfaces of Si to protect Si-MOS devices, which had been fabricated before. GaAs films were then grown by MBE on the areas which were patterned by photolithography. PL intensity of GaAs films in these regions were stronger than that of normal GaAs films grown by MBE. Furthermore it has been found that the performance of Si-MOS devices was maintained after growing GaAs layers. It means that Si-GaAs monolithic integration is feasible.

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## 二极管激光器泵浦的固体激光器

### Diode Laser-Pumped Solid State Laser

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用本所研制的波长为 800~810nm 的二极管激光器锁相阵列泵浦了单块 Nd-YAG 激光振荡器, 观察到了 1.064 $\mu$ m 激光输出。端面泵浦阈值为 4mW, 脉冲能量约 0.1 $\mu$ J, 脉冲能量起伏小于 0.5%。用增益开关技术对单块 Nd 玻璃进行了泵浦, 获得了脉宽 150ns, 峰值功率 200mW 的实验结果。

A phase-locked diode laser array radiated at 800–810nm, fabricated in SIOM, was used to pump a monolithic Nd: YAG oscillator, the laser output at 1.064 $\mu$ m was observed. Endpumped threshold is 4mW. Pulsed energy of the Nd: YAG laser is about 0.1 $\mu$ J and the fluctuation is less than 0.5%. A gain switching of a monolithic LD-excited Nd: glass laser has been tested. The pulse width of 150 ns and peak power of 200mW have been obtained.

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## 大功率半导体激光锁相阵列的实验研究

### Experimental Study of High-Power Phase-Locked Semiconductor Laser Arrays

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本文报导由十个 GaAlAs / GaAs 条形激光器组成的列阵。该器件的典型特性为: 波长 0.86~0.88 $\mu$ m, 阈值电流为 200~250mA, 输出功率大于 200mW, 最高达 247mW (工作电流为 1A), 功率效率为 13%, 单面微分量子效率为 25%。输出光束一般为双瓣, 即 180° 相差的高阶超模, 单束瓣宽 2°, 瓣间角距 3.5~9°。实验中测量了从 20~80℃ 的 L-I 曲线温度特性, 得到特征温度大于 167K, 80℃ 下输出功率大于 100mW。在 50mW 输出功率下 20℃ 时进行了老化试验, 经过筛选, 工作寿命可达 100h 以上。本文还就缩短波长, 超模特性, 导引机构和腔面保护, 增透等问题进行了讨论。

Phase-Locked operation of ten-stripe GaAlAs / GaAs laser arrays. The wavelength of the array is in the range of 0.86–0.88 $\mu$ m and the threshold current is in the range of 200–250mA. The output power is more than 200mW. and its maximum power is 247mW

(at 1A operating current). The overall efficiency is 13% and the differential quantum efficiency is 25–30% (one facet). The far-field pattern is generally a two-lobe beam, this is the highest order supermode of  $180^\circ$  phase-shift. The beam width of each lobe is  $2^\circ$  and the spacing of lobes is in the range of  $3.5\text{--}9^\circ$ . The L-I curves from  $20\text{--}80^\circ\text{C}$  were measured,  $T_0$  was calculated to be more than 167K, and the output power was obtained to be more than 100mW at  $80^\circ\text{C}$ . The L-I curves from  $20^\circ\text{C}$  to  $80^\circ\text{C}$  were measured.  $T_0$  was calculated to be more than 167K, and the output power was obtained to be more than 100mW at  $80^\circ\text{C}$ .

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### 泵浦用 808nm 锁相列阵半导体激光器

#### 808nm Phase-Locked Semiconductor Laser Array for Pumping

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我们采用液相外延技术研制 GaAlAs / GaAs 锁相列阵激光器。器件结构为 Zn 扩散反型结隔离的平面条形，器件由十个激光器组成。中心距  $8\mu\text{m}$ ，相位锁定通过条间区消逝波的耦合实现。我们已获得的 808nm 锁相列阵激光器，其阈值电流为 170mA，输出功率脉冲大于 100mW，连续工作大于 80mW。微分量子效率分别为 19% 和 17% (单面)。工作波长在 806~815nm 范围变化，由脉冲和直流测量的峰值波长之差，可以估算器件的热阻约为  $10\text{--}15\text{K/W}$ 。典型器件的远场分布为双瓣，瓣间距为  $7.9^\circ$ ，每瓣宽度在  $1.7\text{--}1.8^\circ$ 。这是器件在最高阶超模工作的反映。我们研制的 808nm 锁相列阵半导体激光器已用于 Nd-YAG 激光器的泵浦。为了降低热效应的影响，延长器件的工作寿命，采用了脉冲泵浦方式，并用半导体致冷方法调整工作波长，使其与 YAG 的吸收峰匹配最佳。经仔细地调整光路后，成功地获得了 Nd-YAG 激射产生的弛豫振荡。

A GaAlAs / GaAs phase-locked laser array was fabricated by using LPE method. The array consists of 10 Zn-diffusion planar stripe lasers isolated by reversed junction, the spacing between stripe centers is  $8\mu\text{m}$ . Phase-locking is realized through coupling of evanescent fields between laser stripes. The threshold of our 808nm laser array is 170mA. The pulsed output power is more than 100mW and it is more than 80mW for CW operation. The differential quantum efficiency is 19% and 17%, respectively. The lasing wavelength is in the range of 806–815nm. From the difference between the peak wavelengths measured at pulse and CW operations, the thermal impedance of the device is evaluated to be

10–15K / W. The typical far field pattern is a two lobe beam, indicating that the array is operated at the highest order supermode. The angular spacing between lobes is  $7.9^\circ$ , and the beam width of each lobe is  $1.7\text{--}1.8^\circ$ . The 808nm laser arrays have been used to pump Nd–YAG laser. Pulsed pumping was used to depress the thermal effect and extend the lifetime and a T. E. cooler was used to match the wavelength with the absorption peak of YAG. Relaxation oscillation of YAG laser was obtained after the system was adjusted carefully.

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### **Ga<sub>1-x</sub>Al<sub>x</sub>As / GaAs 激光器锁相阵列结温和热阻的实验研究** A Experimental Study of Junction Temperature and Thermal Resistance of

#### **Ga<sub>1-x</sub>Al<sub>x</sub>As / GaAs Laser Phase-Locked Arrays**

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用光谱法测量了 0.86 $\mu\text{m}$  波段、10 条氧化物平面条形锁相阵列激光器的热阻，测得典型器件热阻为 17K / W。利用测得的荧光光谱和激光光谱，对器件的温升、侧向温度分布和激光的锁相作用进行了分析。这些实验结果为进一步研究提高列阵器件的功率输出、工作稳定性和使用寿命提供一些有价值的信息。

The thermal resistance of the laser phase-locked arrays, which have 10 oxide planar stripes and 0.86 $\mu\text{m}$  wavelength, was measured to be 17K / W by spectrum method. Using measured spontaneous and stimulated spectrum, temperature rise lateral temperature distribution and phase-locking in the arrays have been analyzed. These results are a great help to further improving output power, liability and lifetime of the arrays.

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### **GaAlAs / GaAs 激光锁相阵列器件的热特性研究** A Study of Thermal Characteristics of GaAlAs / GaAs Laser Phase-Locked arrays

林岳明 方祖捷

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本文简述列阵器件热特性的实验研究结果, 采用一个简化模型计算了列阵器件的热阻及其腔长和条宽变化的规律, 并与单个激光器的情况进行比较。计算结果表明采用较长腔长和较小条宽可以提高器件的抗热性。

In this paper, the experimental study results on thermal characteristics of laser phase-locked arrays are briefed. The thermal resistance of arrays and its relations with the variations of cavity length and stripe width have been calculated by using simplified model, and compared with a single stripe laser. It is shown that using longer cavity length and narrower stripe width can improve the thermal characteristics of the devices.

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### 人工金刚石热沉的锁相列阵激光器的热特性研究

#### A Study of Thermal Characteristics of Semiconductor Laser Phase-Locked arrays with Diamond Film Heatsink

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用高热导的金刚石薄膜作为热扩展层夹放在器件和铜热沉之间是一种令人感兴趣的新方法, 它可以提高器件的抗热性。本文巧妙地利用镜像法求解金刚石薄膜和铜热沉中的三维热传导方程, 计算了不同金刚石薄膜厚度对器件温升和条间温差的影响。计算结果表明用大于  $50\mu\text{m}$  厚的金刚石薄膜可以显著地获得降低器件温升、减小条间温差的效果。

It is a very attractive method for improving the thermal characteristics using the artificial diamond film with high heat conductivity as a heat-spreading layer, which is bonded between a laser phase-locked array and a copper heatsink. In this paper, a three-dimensional equation of heat conduction in the heatsink consisting of an artificial diamond film and a copper bulk is ingeniously solved by using image method. The temperature rise and distribution of the devices with different diamond thickness is calculated. The result of calculation suggests that more than  $50\mu\text{m}$  diamond film be used for a profound effect.

本文发表在“第四届全国纤维光学与集成光学学术交流会”, 及《吉林大学自然科学学报》, 1990 年特刊, 第 148~150 页

### “大功率半导体激光锁相列阵”研究工作取得初步进展

## Initial Progress of Research Work on “High Power Phase-Locked Semiconductor Laser Arrays”

(光电子主题办公室)

本文报导“863”光电子主题组织的“大功率半导体激光器锁相阵列”评比交流会的情况。测试表明我国的列阵器件的研制工作已取得了可喜的成绩。

A meeting of assess and exchange on “High-power phase-locked semiconductor laser arrays”, organized by “863” subject of Opto-Electronics, is reported in this paper. The measurements show that encouraging progress of research work on laser arrays has been made in our country.

本文发表在《高技术通信》试刊

## 锁相阵列半导体激光器的进展

### The Progress of Phase-Locked Semiconductor Laser Arrays

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本文综述了锁相阵列半导体激光器结构、性能及应用的发展概况,介绍了自己的工作结果。对模式控制,热特性的改善以及工作寿命等问题进行了分析和探讨。

A brief summary on the progress of phase-locked semiconductor laser arrays, including device structures performances and applications, is given in this paper. Results of our research work on the field are presented. Discussions on mode control improvement of thermal characteristics and lifetime are also given.

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## 1.3 $\mu\text{m}$ 光纤外腔主动锁模激光器的实验研究

### Experimental Study of 1.3 $\mu\text{m}$ Active Mode-Locked Lasers with a Fiber Extended Cavity

张位在 张莲英 张影华 谢黄海 方祖捷

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本文报导由多模光纤构成复合腔的  $1.3\mu\text{m}$  半导体激光器的主动锁模实验, 在  $1\text{GHz}$  附近, 测量了光脉冲宽度和波形与调制频率的关系, 观察到锁模发生时脉宽变窄、谱线变宽等现象。

Active mode-locking experiments of an extended cavity  $1.3\mu\text{m}$  semiconductor laser consisting of a laser chip and a piece of multimode fiber were described in the paper. Dependences of the optical pulses width and shape on modulation frequency were measured near  $1\text{GHz}$ . A pulse width narrowing and a spectral line broadening were observed at mode-locking.

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### 半导体激光器中纵向载流子烧孔引起的非对称增益

#### Asymmetric Gain Induced by Longitudinal Spatial Carrier Burning in Semiconductor Laser

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采用微扰方法研究了半导体激光器中驻波型的激射引起的腔内介电常数周期性起伏导致的非线性增益。结果表明当线宽增宽因子  $\alpha \neq 0$  时, 非线性增益谱是非对称的,  $\alpha = 0$  时较容易实现单模工作。

Nonlinear gain caused by dielectric corrugation resulting from the cavity standing wave of a lasing mode in semiconductor laser is investigated using the perturbation approach. The result show that the nonlinear gain spectrum is asymmetric when the linewidth enhancement-factor  $\alpha \neq 0$ , and the possibility of single mode operation is greater at  $\alpha = 0$ .

本文发表在 Electron. Lett., Vol.26, No. 12, p.783, 1990

### 双区共腔(CCTS)双稳激光器的计算机模拟

#### Computer Simulations for a Common-Cavity Two Section (CCTS) Bistable Laser

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本文对双区共腔双稳激光器在均匀电注入和外部光注入条件下的瞬态及稳态特性进行

了计算机模拟。利用注入电流、自发发射耦合因子、外部光注入强度等典型参数分析了速率方程。在这种器件中,双稳和自脉动主要是由于吸收区的可饱和吸收体的作用引起的。一弱光信号可以通过这种激光器进行放大,放大因子与注入光的方向有关。本文还对外部注入光作用下的瞬态响应的一些有意义的结果进行了讨论。

In this paper a computer simulation about the characteristics of steady-state and transient response for a CCTS bistable laser under inhomogeneous electrical injection or external optical injection is reported. The rate equations are analysed in terms of typical parameters, such as electrical injection currents, spontaneous emission coupling factor, external optical injection intensity, etc. It shown that bistability and self-pulsation come mainly from the absorbing section constituting a saturable absorber in this device. A weak optical signal can be amplified by the laser, the amplification factor being dependent on the direction of the incident light. Some interesting results for the transient response under certain external optical injections are also discussed.

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### 光学多层介质膜与多量子阱集成器件

#### Integrated Devices with Optical Dielectric Layers and Multiple Quantum Wells

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本文采用光学传输矩阵元的方法设计了一种集成型反射式多量子阱器件,并给出了理论计算结果。采用 MOCVD 生长方法制作了该器件,它由 n 型多层增透介质膜、i 型多量子阱、p 型多层高反射率介质膜所组成。测试了该器件的光电流谱和反射率谱,并与理论结果作了比较,二者附合得很好。这种器件可以发展成兼具调制、开关、双稳复合功能的反射式集成器件。

The optical transmission matrix method has been used to design an integrated reflection MQW device. The device was made in a MOCVD equipment by growing an MQW between a high-reflectance stack and anti-reflectance layers. The photocurrent and reflectivity spectra of the device have been measured and compared with the theoretical calculation results. Close agreement was demonstrated among them. It can be expected to make an integrated reflection device with complex functions, such as modulation, switching and bistability.

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**GaAs / GaAlAs pnpn 负阻激光器中的光开关、光双稳特性**  
**Optical Bistability and Switching Characteristics of a GaAs / GaAlAs**  
**pnpn Negative Resistance Laser**

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本文首次报道了利用 pnpn 型 GaAs / GaAlAs 激光器件实现光双稳及光开关工作的实验结果,以及采用双光晶体管模型对于器件的光双稳、光开关作用原理的一般性分析。

We report for the first time some experimental results on the optical bistability and switching characteristics of a pnpn type GaAs / GaAlAs laser device, and based on the double phototransistor model, a general analysis is given to the physical description about the optical bistability and switching operations in the device.

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**光触发 GaAs / GaAlAs 异质结负阻激光器**  
**Light-Activated GaAs / GaAlAs Heterostructure Negative Resistance**  
**Lasers**

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采用 GaAs / GaAlAs 多层液相外延技术研制成一种光触发异质结负阻激光器。文中简述了器件的工作原理和某些特性。

A light-activated GaAs / GaAlAs heterostructure negative resistance laser has been made by horizontal liquid-phase epitaxial growth. The operation principle and some of the characteristics of the device are described.

本文发表在《中国激光》，第13卷，第7期

**阶梯衬底内条形可见光半导体激光器及其列阵**  
**Terraced Substrate Inner Stripe Visible Semiconductor**



## Laser and Its Arrays

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一种新结构半导体激光器, 阶梯衬底内条形, 及其列阵具有非常简单的制做工艺。发射波长在 750~780nm, 平均阈值电流 30~40mA, 直到 4mw 下工作超过 3000h 阈值电流几乎不变。相应的锁相列阵具有远场单峰, 直流工作  $6^\circ$  半宽, 脉冲工作  $2.4^\circ$  半宽。

A new structure for semiconductor lasers, Terraced Substrate Inner stripe (TSIS) laser, and its arrays are reported with very simple fabrication processes. The laser, emitting in the range of 750–780nm, have average current threshold of 30–40mA and maintain singletransverse mode operation up to 20mW. The life tests show that the new type lasers have almost no threshold change after 3000h aging at 4mW CW operation. The TSIS laser arrays have clean single lobe far-field patterns with full width at half power of  $6^\circ$  in CW operation and  $2.4^\circ$  in pulsed operation.

本文发表在 IEEE. Journal of Quant. Electron. QE-26, No.3, 1990

## 混合抛物面反射二维面发射可见光半导体激光器

Hybrid Parabolic Reflector Two Dimensional Surface

Emitting Visible Semiconductor Laser

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研制成功一种新型混合式面发射半导体激光器。它由水平端发射列阵激光器和蒸金 GaAs 反射抛物面构成。已实现的二维六单元面列阵激光器室温脉冲峰值功率达 230mW。

A new type of Surface emitting Semiconductor laser diodes is fabricated. It consists of end emitting laser arrays and Au coated GaAs tilt reflector. A six element two dimensional laser array fabricated by the authors emits a peak power of 230mW under pulse condition.

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## 中国的激光安全防护

Laser Sefety in China

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从安全的观点来看,应把激光器看作为一类定向释能武器。因为激光的光子简并度猛增了约 20 个数量级。量变引起质变。加上激光技术的参量繁多,它与各种生物组织的相互作用产生复杂的生物效应。弄清激光的生物效应是个难题,只能逐步深入。这对生命科学具有重大意义。在中国不仅深入研究了黄种人的激光安全标准,而且还开展了激光卫生物理学研究。激光安全问题已引起广泛的注意。随着时间的推移,接触激光的人员不仅人数增加而且激光研究者接触激光的时间也持续延长,他们的眼晶状体混浊率比居民高出 2~4 倍。作者预见,根据最近太阳光可引起白内障的理论,如不认真防护,激光辐射可能使老年性白内障提前发生。我们用 SSY-1 型激光能量仪测试了激光散射光分布的情况,讨论了采用“激光安全器”和防“漫反射激光护目镜”等防护措施。

From the point of view of safety, lasers may be seen as a kind of directed energy weapons since the photon degeneracy of lasers has been increased about 20 orders of magnitude. Change in quantity will cause change in quality. In addition, lasers have many parameters. Their interaction with tissues causes complicated biological effects. Its understanding is getting deeper step by step. We have done in China in-depth research on the laser safety standard of the yellow race, and have opened up the way for investigation on laser hygienic physics. Laser safety has recently attracted people's widespread attention. Now the number of people contacting lasers and the contacting duration of laser researchers are increasing. The opacity ratio of the crystalline of the human eyes is 2-4 times higher than that of the ordinary people. The authors predict that the laser radiation may induce senile cataracts prematurely which is going on hiddenly and unconsciously. According to the theory of cataract formation by sun light, the intensity of scattered laser beams measured by using SSY-1 laser energy scattermeter, and the problems are discussed involving the protection against the scattering laser light, including the adoption of laser safeguard measures, et al.

本文发表在“第一届国际激光治疗学会学术报告会”,1990 年 10 月 28 日

### 准分子激光对 Al、Au 刻蚀的技术研究

#### Technological Research on Induced Etching of Al, Au with Excimer Laser

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本文报导了准分子激光对 Al、Au 等金属的直接刻蚀和诱导刻蚀技术,给出了刻蚀过程中激光能量密度、刻蚀速率及反应气体压力之间的关系,分析讨论了准分子激光对

Al、Au 的刻蚀机理和规律。

The technology of direct and induced etching of Al, Au with excimer laser is reported in this paper. The functional relations between laser energy density, etching rate and pressure of reaction gas are given. And the mechanism of the etching of metals by excimer laser is discussed.

本文发表在《激光技术》，第 3 期，1990 年

### **InP 材料准分子激光 APD 刻蚀特性**

#### **Characteristic of APD Etching InP by Excimer Laser**

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本文报告了利用波长为 308nm 的脉冲准分子激光，在空气中成功地实现了对半导体材料 InP 的光解剥离刻蚀。其实验刻蚀能量密度阈值约  $390\text{mJ}/\text{cm}^2$ 。同时，提出了一个简单的物理模型，解释了刻蚀能量密度阈值和刻蚀速率对实验数据及材料参数的依赖关系。

It is reported that semiconductor InP can be successfully etched in air at a pulsed excimer laser wavelength of 308nm, the experimental fluence threshold is about  $390\text{mJ}/\text{cm}^2$ . A simple model to explain the etching process is proposed. It relates fluence threshold and etching rate to experimental data and material parameters.

本文发表在“89’光电子器件与集成技术年会”，北京，1989 年

### **高灵敏度的 ps 光电取样系统**

#### **A High Sensitive Picosecond Optoelectronic Sampling System**

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本文报导 ps 光电取样系统，该系统由超短光脉冲源、ps 光电导开关、可变光学延迟线、锁相放大器和 X-Y 记录仪组成。在该系统中，光源用锁模  $\text{A}_r^+$  激光同步泵浦染料激光器，染料激光脉宽是 2.5ps，平均输出功率为 30mW；SOSps 光电导开关作取样门。整个系统的时间分辨率和电压灵敏度取决于光源和光电导开关的性能。用硅离子辐照损伤 SOS 基片，并蒸镀微带线电极制作光电导开关，开关的响应时间小于 7ps，输出几十毫伏

的电脉冲。系统的时间分辨率为几 ps, 电压灵敏度为  $10\mu\text{V}$ 。使用该系统测量了高速光电探测器和微带传输线的时间特性, 实验证明该系统是测量快速光电子和电子器件、固体电路和材料的时间特性的有力工具。

In this paper, we describe a optoelectronic sampling system which consists of an ultrashort pulse laser, a psecosecond photoconductive switch, a variable light delay line, a lock-in amplifier and a X-Y recorder. In the system, the source is a CW synchronously pumping mode-locking Dye laser with pulse width is 2.5ps at an average output power 30mW. The photoconductive switch acts as a sampling gate. The system's time resolution and voltage sensitivity depend on the performance of the switch and the source. Using SOS chip bombarded by Si ions and evaporating microstripline with a gap on it. We have developed some photoconductive switches with on-off time of 6-7 ps and with electric pulse output of tens mV. The system with time resolution of several ps and sensitivity of  $10\mu\text{m}$ . We have adopted this system to determine the time characteristics of high speed photodiodes and microstrip times. It is an ideal tool to measure the time characteristics of high photoelectronic or electronic devices, solid circuits and materials.

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### 声光锁模 $\text{Ar}^+$ 激光器的最新研制结果

#### The Latest Developing Results on Acousto-Optical Mode-Locked

#### Argon Ion Laser

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本文研制了一种新型声光锁模器。将拉曼—奈斯型声光调制器, 与光棱镜和腔全反镜三者合一, 由于调制器与全反镜距离很近, 经反射镜反射再次通过调制器的各级衍射光在光轴方向发生相长干涉。当射频驱动源功率  $< 1\text{W}$  时就可以实现光强的 100%调制和 60%的衍射效率。这降低了对器件的工艺要求并且增加了器件的稳定性; 合为一体不仅降低了插入损耗而且减小了体积。

本文首次采用 PS 光电导采样技术观测  $\text{Ar}^+$ 激光脉冲的时域特性。光电导采样系统用光电导开关作取样门和光探测器, 自制光电开关的响应时间  $< 10\text{ps}$ , 配以光学可变延迟器, 锁相放大器和记录仪; 记录下  $\text{Ar}^+$ 激光脉冲所激发的电脉冲的相关函数, 由于整个测试系统的时间分辨率  $< 10\text{ps}$ , 很容易将激光器调到最佳工作状态。

用自制新型锁模器和上述测量方法, 我们获得了 60ps 的  $\text{Ar}^+$ 光脉冲, 这是用声光主动锁模得到的最短  $\text{Ar}^+$ 光脉冲。

A new model acousto-optic mode-locked device has been developed. A Raman-Nath acousto-optic modulator, a prism and a resonator mirror share a piece of quartz glass. Because the distance between the modulator and the mirror is very close, after passing through the modulator twice each order of diffraction light in axial direction interferes constructively. Setting up the radio power 1W, intensity modulation depth and efficiency of the diffraction are 100% and 60% respectively. It decreases the requirement for fabricated art and increases the steadiness. Uniting three optical elements into one, the loss of insertion is lower and the volume is less. For the first time in the world we have detected time domain characteristics of Argon ion laser pulse by using ps photoconductive sampling technique. In this system a photoconductive switch is used as a sampling gate another as an optoelectronic detector. The response time of the switches is less than 7ps and the time resolution of the system with a variable optical delay line, lockin amplifier and recorder is less than 10ps. Using this technique it is easy to align cw ps pulse lasers into optimum states and 60ps pulses which are the shortest from acousto-optic active mode-locked Argon ion lasers have been obtained.

本文发表在《激光与红外》，第4期，1990年

### 利用 ps 和光电导取样技术测量超快光电探测器的响应时间和联接件的色散展宽

#### Measurement of the Response Time of Ultrafast Photoelectric Detectors and Dispersive Broadening Effect of Connector with Picosecond Photoconductive Sampling Techniques

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为了测量超快器件和材料的响应时间，我们研制了一套 ps 光电导取样测量系统。这个系统中，同步泵浦染料激光做为光源，SOS 光电导开关做取样门。实验证明该系统的时间分辨率为 7ps，灵敏度为  $10\mu\text{V}$ 。使用该系统，我们测量了美国光谱物理公司生产的 403B 超高速光二极管，其中一个上升时间为 52ps，时间响应曲线的宽度 (FWHM) 为 73ps，另一个 (No.509) 的上升时间为 60ps，时间响应曲线的半宽度为 81ps；测量了德国制作的雪崩二极管 (BPW-28A)，它的上升时间是 124ps，响应曲线的宽度是 331ps；测量的 Ge-APD (中科院半导体所) 上升时间为 81ps，响应曲线宽度为 210ps。我们还测量了联接件的色散展宽，10ps 的电脉冲通过一个同轴联接头和长度分别为 3cm、9cm 和 18cm 的同轴电缆线时分别展宽为 18.6ps、21.4ps 和 27ps。

For measurement of the responses time of ultrafast defectors and some materials, we

have developed a picosecond photoconductive sampling system with a dye laser, synchronously pumped by mode-locking Argon Ion Laser as the source and with a SOS photoconductive switch as the sampling gate. It has been demonstrated that this system has time resolution of 7ps and Voltage sensitivity of  $10\mu\text{V}$ . Using it, we have measured the response time of 403B ultra-high-speed photodiode (American Spectra-physics Company). One's (No.48) risetime is 52ps and the width of the time response curves (FWHM) is 73ps; another's (No.509) risetime is 60ps and the half width of the time response curves is 80ps. We have also measured the response time of an avalanche diode (BPW-28A) made in Germany. Its risetime is 124ps and the half width of the response curves (FWHM) is 331ps. Then we have measured the response of a Ge-APD made in the Institute of Semiconductor, Academia Sinica. Its risetime is 81ps and the half width of the response curves (FWHM) is 210ps. The dispersive broadening effect of the connector have been tested. When electrical pulses of 10ps are transmitted through a coaxial connector and cable transmission lines with lengths 3cm, 9cm and 18cm respectively, these pulses will be broadened to 18.6ps, 21.4ps and 27ps respectively.

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### 一种新型的超短脉冲相关测量仪

#### A New Model Autocorrelator for Measuring Ultra-Short Pulses

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该 ps 电脉冲、ps 光脉冲相关测量仪用离子辐照损伤 SOS 片制作的光电导开关作取样门 (响应时间  $<10\text{ps}$ ), 用锁模  $\text{Ar}^+$  激光器同步泵浦染料激光器作激发和取样光源 (脉宽  $<2\text{ps}$ , 570~620nm 连续可调谐, 82MHz)。将激光分为两束, 一束经聚焦照射待测器件, 产生的电脉冲加到取样门上; 另一束经过一个可变光学延迟器聚焦到取样光电导开关上, 用直流电机带动连续改变光学延迟器, 用锁相放大器和记录仪记录待测器件产生的电脉冲和取样电脉冲的相关曲线。由此可以确定待测器件的响应时间。如果用已知光电导开关作光探测器, 可以测量未知光脉冲的时间特性。相关测量仪的时间分辨率为 10ps, 测量范围为 0~250ps, 适用波长为可见光, 光强灵敏度为 15mW。

用该相关测量仪已经检测了自制光电导开关速度  $<10\text{ps}$ , 在国内首次检测了美国光谱物理公司的 403B 快速探测器上升时间为 52ps, 测量了中科院半导体所研制的锗高速雪崩光电探测器, 其上升时间为 85ps, 脉宽为 221ps。

In the autocorrelator for measurement of ultrashort electric and optic pulses, the sampling gate is a photoconductive switch made from radiation-damaged SOS material and

the laser pulse source is a synchronously pumping Dye laser (pulse width  $< 2\text{ps}$ , tunable range 570–620nm repeated rate 82MHz). A train of laser pulses is divided into two. The chopped beam (exited beam) is used to illuminate the devices to measure. Its photoelectronic response pulses are fed into the sampling gate, the photoconductive switch; the sampling beam passes through a variable optic delay line driven by a D.C. motor then it illuminates the switch. The sampling signals are amplified by the LIA and recorded by X-Y recorder. From the correlation curves recorded, we can determine the characteristics of the devices under test. If another photo-conductive switch acts as a optoelectronic detector the correlator can be used to measure the width of ps optic pulses. Its time resolution is 10ps, the measurement range is 0–250ps and the intensity required is at least 15mW. Using it we have measured the on-off time of homemade photoconductive switches, the rise-time of 403B ultrafast photodiode and the risetime of the Ge-APD made in the Institute of Semiconductor, Academia Sinica.

本摘要发表在《激光与红外》，第4期，1990年

### SOSps 光导开关研制

#### Study of ps Photoconductive Switch on Silicon-on-Sapphire films (SOS)

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用具有高缺陷密度的半导体材料制成光电导开关。它可用来产生 ps 光脉冲，作为 ps 光脉冲探测器，并且用它来实现 ps 精度光电取样测量。这个技术是研究高速光电器件和电子器件的重要工具。

我们选用高能粒子硅轰击过的 SOS（蓝宝石衬底外延硅膜）材料作为半导体光电导层，为使纵向缺陷密度分布均匀，选用三次连续注入方法，用控制注入剂量来控制载流子寿命，它决定器件响应速度。用低温短时退火提高器件灵敏度（而不影响响应时间）和改善器件稳定性。采用高灵敏度 ps 光电取样技术测量器件输出电脉冲响应时间，电脉冲幅度和光电导材料平均迁移率。我们研制的光电导开关输出电脉冲半宽值（FWHM）小于 8ps，电脉冲幅度在 10mV 量级，载流子迁移率  $\mu \approx 10\text{cm}^2/\text{V} \cdot \text{s}$ 。

The high-defect-density semiconductors are used in ps photoconductive switches. Applications of these switches are:

- 1)picosecond electrical pulse generators.
- 2)picosecond optical pulse detectors.
- 3)sampling gates with picosecond time resolution.

It is an useful tool to measure the time characteristics of high speed photoelectronic or

electronic devices.

We adopted the radiation damaged SOS as photo-conductive materials. Each sample was irradiated with Si ions of three different energies and doses in order to achieve approximately homogeneous damage across the film thickness. The damaged samples were annealed at a low temperature. It may increase the sensitivity (don't change its response time) and improve its steady.

A high sensitivity picosecond optoelectronic sampling system was used to measure the response of the photoconductive switch fabricated on SOS. Electrical pulses with 8 ps (FWHM) are achieved. The amplitudes of output electrical pulses are about several ten mV. The mobility of photocarries is about  $10 \text{ cm}^2 / \text{Vs}$ .

### 用棱镜耦合器测量石榴石液相外延薄膜的折射率和厚度

#### Refractive Index and Thickness Measurement of Garnet Liquid Phase

#### Epitaxy Film by Prism Coupler

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(华中理工大学固体电子学系)

本文研究了用棱镜耦合器测量石榴石液相外延薄膜折射率和厚度的方法。与传统方法相比,此方法有以下优点: 1) 精度高, 2) 无需复杂数据处理过程, 就可以同时测量石榴石外延膜的折射率和厚度。其薄膜折射率测量误差为  $\pm 0.0055$ 。薄膜厚度的相对误差为  $2.8 \times 10^{-3}$ 。最后我们推导了计算薄膜厚度和折射率测量误差的计算公式, 分析了测量误差的来源, 发现影响测量精度主要因素是同步角测量。

A method for measuring the refractive index and thickness of garnet liquid phase epitaxy film by using prism couplers is studied. In comparison with conventional methods, the one described here has following advantages: 1) High precision, 2) The refractive index and thickness of garnet liquid phase epitaxy film can be obtained simultaneously without a complicated data reduction procedure. The measurement errors of the index and thickness are about  $\pm 0.0055$  and  $2.8 \times 10^{-3}$  respectively. At last, we deduce the measurement error formulas. By means of these formulas, we analyse the source of measurement errors, and find that the measurement error is mainly due to synchronous angle.

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### 窄线宽低光损耗高掺 Bi 石榴石薄膜外延生长

#### Epitaxial Growth of Highly Bi-Substituted Garnet Film with



## Narrow FMR Linewidth and Low Optical Absorption Loss

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本文研究了以钆镓石榴石 (GGG) 为基高掺 Bi 液相外延石榴石薄膜生长规律, 发现生长温度对制备性能优异薄膜有很大影响。测得其铁磁共振线宽为 0.6Oe, 是目前有关报导中最小的。在波长 633nm 下比 Faraday 旋转角为 15000 / cm, 并给出了光吸收系数随波长变化关系曲线。当微波频率为 4.0GHz 时, 在所制备磁光薄膜上实现了静磁表面波传输, 并观察到了延时为 180ns, 带宽为 400MHz 的静磁表面波延时信号。

The epitaxial growth regularities of highly Bi-substituted iron garnet films on gadolinium gallium garnet (GGG) substrates by LPE technique are investigated in this paper. The influence of growth temperature on preparation of film is described. The ferromagnetic resonance (FMR) linewidth of 0.6 Oe is measured, which is the smallest value reported up to date for such films. The specified Faraday rotation of 15000 / cm at the optical wavelength of 633 nm is measured. The optical wavelength dependence of the optical absorption coefficient is given. At the microwave frequency of 4.0 GHz, magnetostatic surface wave (MSSW) propagations are conducted in the prepared films, and MSSW delay signal with the delay time of 180ns and the bandwidth of 400 MHz is observed.

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## 高 Bi 含量的 RIG 的外延生长

### Epitaxial Growth of Highly Bi Substituted RIG

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本文研究了高 Bi 含量的磁性石榴石薄膜 (LuBi)<sub>3</sub>Fe<sub>5</sub>O<sub>12</sub> 的液相外延生长规律, 提出了满足静磁波—光相互作用要求的磁光薄膜组分设计思想及有关工艺参数的选择。文中分析了生长温度对薄膜质量的影响, 确定最佳的生长温度大约在 1033K 到 1053K 之间。当微波频率为 4.0GHz 时, 在所制备样品上观察到延迟时间为 180ns, 带宽为 400MHz 的静磁表面波延迟信号。在波长 633nm 下测量比 Faraday 旋转角为 15000 / cm。

LPE growth regularities of highly Bi substituted lutetium iron garnet films are discussed, and the composition design ideas of the magneto-optical films fulfilling the requirements of the interactions between magnetostatic waves and optical waves and selections of the relative experimental parameters are proposed in this paper. The influences of

growth temperatures on film qualities are studied, and the optimum temperature range is between 1033K and 1052K. At the microwave frequency of 4.0GHz, MSSW delay signal with the delay time of 180 ns and the bandwidth of 400 MHz is detected. The specified Faraday rotation of 15000 / cm at the optical wavelength of 633 nm is measured.

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### Fe 离子价态对磁光薄膜光吸收谱的影响

#### Influences of Fe Ion Valences on Optical Absorption Spectra of Magneto-Optical Films

何华辉 苏 钧

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对稀土铁石榴石薄膜光吸收谱的研究表明, 在  $1\mu\text{m}$  到  $10\mu\text{m}$  的光波长范围内, 所观察到的光吸收主要来源于八面体和四面体上的  $\text{Fe}^{3+}$  跃迁以及氧离子与铁离子间的电荷跃迁。本文借助于 XPS 谱图, 对  $\text{Fe}^{3+}$  离子的含量比例作了定量分析, 揭示了氧化处理对光吸收的影响。从铁离子 XPS 谱图可见, 氧化后  $\text{Fe}^{2+}$  谱线能量分裂比氧化前减少, 说明自旋—轨道的耦合减弱带来的是光吸收减少。

As shown in the optical absorption spectra of rare earth iron garnet films, the absorption detected in the optical wavelength range of  $1\mu\text{m}$  to  $10\mu\text{m}$  mainly origin from the charge transfer of  $\text{Fe}^{3+}$  ions in octahedral and tetrahedral sites and the optical transitions between crystal field levels of Fe-O cluster. By means of X-ray photoelectron spectroscopy (XPS), the relative proportions of iron ion contents are quantitatively determined, and the influence of oxidizing treatment on optical absorption is revealed. It is indicated in the XPS spectra of Fe ions that the XPS spectra of  $\text{Fe}^{2+}$  decreases compared with the case of no oxidizing, which reflects the spin-orbit coupling diminishes, so that the optical absorption decreases.

本文发表在《第七届全国磁学会议论文集》

### 磁性石榴石薄膜的液相外延生长模型

#### LPE Growth Model of Magnetic Garnet Film

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本文从反应—扩散方程出发,建立了稀土铁石榴石薄膜的液相外延生长模型。该模型与一般相应的生长模型的不同之处在于它不仅可以分析薄膜的生长速率,而且可以研究外延生长过程中溶质在熔体中的浓度分布。文中分析了  $\text{Yb}_2\text{O}_3$  和  $\text{Fe}_2\text{O}_3$  浓度在液相外延生长过程中随温度的变化及两种浓度在模拟坩埚剖面上随基片旋转速率的变化规律,所得结果与实验相吻合。本文模型可以进一步扩展到分析掺杂石榴石薄膜材料的外延生长。

Liquid phase epitaxy (LPE) growth model of rare earth iron garnet film is established on the basis of reaction—diffusion equation in the present paper. Unlike other corresponding growth models, the model can not only analyze the film growth rates, but also determine the solute concentration distributions during LPE process. Here, the concentration changes of  $\text{Yb}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  ion solution versus temperature and rotation rate of substrate is discussed, and the theoretical and experimental result are in agreement. This model can be extended to the LPE system of doping magnetic garnet film.

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## YIG 薄膜中静磁模式和交换模式铁磁共振测量和理论分析

### The FMR Measurement and Theoretical Analysis on Magnetostatic and Exchange Modes in YIG Film

周世昌 李少平 何华辉  
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本文给出了各向异性介质中偶极交换自旋模式色散关系以及交换作用对静磁波铁磁共振谱的影响。得到了不同情况下波矢量垂直膜面一系列近似公式。在二级近似时,所有垂直膜面的波矢量都与交换有关。另外,当各向异性存在而交换能比偶子能小时,利用一级近似可以得出考虑交换作用静磁波较精确色散关系。在均匀低场处测量薄膜铁磁共振谱,其实验结果与考虑相互作用 D—E 理论符合。

A dispersion relationship for dipole—exchange spinwave mode in anisotropy medium and the effect of the exchange interaction on magnetostatic wave using the ferromagnetic resonance spectrum are described here. A series of approximation formulas of wave vectors normal to the film in different cases is given. In approximation of 2nd degree, all the three wave vector normal to the film are related to the exchange parameter. On the other hand, when only anisotropy energy exists and exchange energy is fairly smaller than dipolar energy, in the approximation of 1st degree, a rather precise magnetostatic spin wave dispersion relation modified the exchange interactions. FMR on the thin film were measured on the low field side of the uniform resonance. Quantitative agreement between the experimental

data and theory modified by exchange interaction is obtained.

本文发表在《第九届国际铁氧体会议论文集》

### **(La, Ga):YIG 单晶薄膜的铁磁共振研究**

#### **A Study on Ferromagnetic Resonance for (La, Ga):YIG Single Crystal Film**

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(华中理工大学固体电子学系)

本文研究了用于微波器件 (La, Ga):YIG 单晶薄膜的铁磁共振特性。分析了共振线宽和各向异性。微观结构的关系。发现单晶各向异性来源于薄膜生长过程由衬底和薄膜失配引起。线宽最大值产生于薄膜表面凹坑散射。当磁场的方向平行于薄膜表面时, 所观察到铁磁共振吸收谱与考虑立方和单轴各向异性 D—E 理论计算结果一致。在实验中, 我们在均匀共振低场处发现有不规则表面模式激励区域。

The FMR behavior of (La, Ga): YIG single crystal film used in microwave devices is investigated. The relations between the anisotropy the FMR linewidth and parameters of microstruct are analysed. The uniaxial anisotropy originates in the film growth process and result from substrate—film lattice mismatch. The maximum linewidth arises from the complete absence of surface pit scattering in the film. When the direction of magnetic field parallel to the film surface, quantitative agreement can be obtained between most of the observed lines and the results of calculations based on Domon—Easbach (DE) theory modified by cubic and uniaxial anisotropy.

本文发表在《第九届国际铁氧体会议论文集》

### **多层 YIG / GGG 薄膜的外延生长技术**

#### **Liquid Phase Epitaxy Technique for Multiple YIG / GGG Film**

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(华中理工大学固体电子学系)

本文研究了多层 YIG / GGG 膜液相外延生长技术, 探讨以 GGG (钇镓石榴石) 为基外延生长 La: YIG 薄膜。GGG 薄膜的生长规律。描述了 La 含量和薄膜晶格常数  $Pb^{2+}$  和  $Pb^{4+}$  含量和过冷度  $\Delta T$  的关系。当生长温度  $T_0$  大于饱和温度  $T_s$ , GGG 薄膜熔解。给出了复合层状 (介质—磁性—介质—磁性) 单晶薄膜的设计方法和实验结果。发现只有当

YIG—GGG 以及 GGG—YIG 晶格匹配时, 才能在 GGG 衬底上生长出多层膜。

This paper studies the liquid phase epitaxy (LPE) technique for multiple YIG / GGG film. The LPE growth regularities of La: YIG film and GGG film are investigated. The relationship between La content and lattice constant of the film as well as relationship between content of  $Pb^{2+}$  and  $Pt^{4+}$  supercooling temperature  $\Delta T$  are described. When the growth temperature  $T_g$  was larger than the saturation temperature  $T_s$ , the GGG film was solubilized. The design methods and the experimental result of the multiple layers, i.e. "dielectric—magnetic—dielectric—magnetic" single crystal films are given. Only if the lattice mismatches for YIG on GGG and GGG on YIG are very small the multiple layer film can be grown on a GGG substrate.

本文发表在《第九届国际铁氧体会议论文集》

### RRH / VLP—CVD 生长的 $Ge_xSi_{1-x}$ / Si 应变层超晶格结构性质

#### Structural Properties of $Ge_xSi_{1-x}$ / Si Strained Layer

#### Superlattices Grown by RRH / VLP—CVD

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本文报道了用快速辐射加热, 超低压化学气相淀积 (RRH / VLP—CVD) 首次生长了  $Ge_xSi_{1-x}$  / Si 应变层超晶格, 用 X 射线衍射, 喇曼散射测量, 以及透射电镜观察研究了  $Ge_xSi_{1-x}$  / Si 应变层超晶格结构性质。对生长在硅 (111) 衬底上的超晶格的  $Ge_xSi_{1-x}$  合金层观察应力产生的有序结构。

In this paper, we report for the first time the strained layer  $Ge_xSi_{1-x}$  / Si superlattices grown on Si substrate by rapid radiant heating, very low pressure chemical vapor deposition (RRH / VLP—CVD). We have studied the structural properties of strained layer  $Ge_xSi_{1-x}$  / Si superlattices using X-ray diffraction and Raman scattering measurements together with transmission electron microscopy observations. A strain-induced ordering transition in the  $Ge_xSi_{1-x}$  alloy layers of the superlattice grown on Si(111) substrate in X-ray diffraction measurement have been observed.

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## **$\text{Ge}_x\text{Si}_{1-x} / \text{Si}$ 应变层超晶格与异质结构**

### **The Structure of $\text{Ge}_x\text{Si}_{1-x} / \text{Si}$ Strained Layer Superlattices and Heterostructures**

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首次用快速辐射加热, 超低压化学气相淀积 (RRH / VLP-CVD) 生长了  $\text{Ge}_x\text{Si}_{1-x} / \text{Si}$  应变层异质结构, XPS 和 AES 分析结果指出: 外延层是一组分均匀、结合能与体 Si、Ge 相同的纯 GeSi 合金层, XRD 谱表明  $\text{Ge}_x\text{Si}_{1-x}$  外延层为一高质量的单晶应变层。还用 RRH / VLP-CVD 方法生长了  $\text{Ge}_x\text{Si}_{1-x}$  超晶格。TEM、XRD 和 Raman 测量结果显示为很好的应变层  $\text{Ge}_x\text{Si}_{1-x} / \text{Si}$  超晶格结构。

A series of GeSi / Si strained layer heterostructure grown by Rapid Radiant Heating. Very Low Pressure Chemical Vapor Deposition (RRH / VLP-CVD) on Si(100) substrate have been studied for the first time. The results of XPPS and AES indicate that the epilayer is a pure GeSi alloy with a homogenous composition and the values of binding energy are the same as those of bulk Si and Ge respectively. The XRD spectra show that the epilayer is a high quality single crystal with a lattice plane spacing different from that of the bulk GeSi alloy predicated by Vegard's law and that measurement from poly-crystalline diffraction, which means the epilayer is a strained film. The RRH / VLP-CVD method has been developed to grow the  $\text{Ge}_x\text{Si}_{1-x} / \text{Si}$  superlattices. The results of TEM, XRD and Raman measurements exhibit a fine strained layer  $\text{Ge}_x\text{Si}_{1-x} / \text{Si}$  superlattice structure.

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## **Si / Ge 异质结构界面的 XPS 和 AES 分析**

### **XPS and AES Analysis of the Interface of Si / Ge Heterostructures**

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本文研究了快速辐射加热, 超低压化学气相淀积 (RRH / VLP-CVD) 生长的 Si / Ge (111) 异质结构。X 射线射和 RAMAN 散射谱指出外延层为一结构很好的单晶硅层。XPS 和 AES 分析表明生长温度 700 度以上的外延硅层与 Ge 衬底之间存在  $\text{Ge}_x\text{Si}_{1-x} / \text{Si}$  ( $0 < x < 1$ ) 合金过渡区, 形成 Si- $\text{Ge}_x\text{Si}_{1-x}$ -Si 异质结构, 发现过渡区氧含量很低, Si 层中存在间隙态氧。

In this paper, a Si / Ge(111) heterostructure grown by rapid heating, very low pressure chemical vapor deposition (RRH / VLP / CVD) has been studied. XRD and Raman scattering have shown that the epilayer is a single crystal Si film with good crystalline structure. The results of XPS and AES analysis indicate that there is a transition region composed of  $\text{Ge}_x\text{Si}_{1-x}$  ( $0 < x < 1$ ) alloy material between the epilayer and substrate, so that a Si- $\text{Ge}_x\text{Si}_{1-x}$ -Ge multilayer heterostructure has been obtained. In the transition region, the oxygen concentration is very low, which is perhaps caused by Ge atoms in the epilayer. In the Si epilayer, oxygen atoms are found in the interstitial sites in the lattice.

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### 锗硅超晶格研究

#### Study of $\text{Ge}_x\text{Si}_{1-x}$ / Si Superlattices

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采用 Raman, XRD, TEM 和 SEM 研究了以快速辐射加热、超低压 CVD (RRH / VLP-CVD) 在 Si 衬底上生长的 GeSi / Si 应变层超晶格的结构性质, 结果表明: 用 RRH / VLP-CVD 生长得到了相干应变的 GeSi / Si 超晶格; GeSi / Si 应变层超晶格应变结构模式依赖于 Si 层与 GeSi 层的厚度; 观察到 Si 层与 GeSi 层同时存在应变与只在 GeSi 层存在应变的两种应变结构模式; 在 Si (111) 衬底上生长的 GeSi / Si 应变层超晶格的 XRD 测量中, 观察到由 GeSi 合金层有序化引起的反常 X 射线衍射峰。

We have studied the structural properties of GeSi / Si strained layer superlattice grown on Si substrate by Rapid Radiant Heating and Super Low Pressure Chemical Vapor Deposition (RRH / VLP-CVD) using Raman scattering, XRD, TEM, and SEM. The results indicate that the coherently strained  $\text{Ge}_x\text{Si}_{1-x}$  superlattice can be grown by RRH / VLP-CVD. The model of strained structure of superlattice depends on the thickness of GeSi alloy layer and Si layer. Two models of strained structure of superlattice have been observed. A model structure in  $\text{Ge}_x\text{Si}_{1-x}$  alloy of  $\text{Ge}_x\text{Si}_{1-x}$  / Si strained layer superlattice grown on Si(111) substrate has been observed in XRD measurement.

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## 用非腐蚀性气体对 InP 进行了干法腐蚀

### Dry Etching of InP with Non-Corrosive Gases

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以往对 InP 的干法腐蚀均采用含强腐蚀性的氯基气体, 而且需要较高的工艺温度。这对于器件本身、工艺过程以及设备维护都是不利的。本文介绍采用  $\text{CH}_4/\text{H}_2$  气体全面深入地研究对 InP 的反应离子刻蚀, 各种工艺参数对腐蚀结果的影响和选取最佳条件以制作微米结构。

气体成份配比是影响腐蚀效果的最主要的因素。 $\text{CH}_4/\text{H}_2$  含量的变化对蚀速有明显的作用。InP 在纯  $\text{H}_2$  中, 腐蚀速度很慢。随着  $\text{CH}_4$  的加入, 蚀速作直线上升, 说明蚀速与对 InP 起着腐蚀反应的活性粒子的数量成比例。在中等气压下, 蚀速随  $\text{CH}_4$  含量的增加而加快, 达到峰值后缓慢下降。这是由于反应过程中生成聚合物或碳等非挥发性淀积物, 妨碍了腐蚀反应的进程。腐蚀气压对蚀速也有一定的影响。在低气压下, 蚀速与气体含量的关系有类似上述的变化趋势, 但蚀速有所降低 (因为反应粒子数量减少了), 而且腐蚀的截止限也加长了。蚀速对气体总流量或射频功率也有不同程度的影响。腐蚀断面轮廓和表面形貌与工艺参数有密切关系。由于淀积物伴随着整个腐蚀过程, 因而在高含碳量情况下会形成外倾型侧墙。低气压下由于加强了离子的轰击能量, 腐蚀断面侧墙趋于垂直。合理选用腐蚀参数, 可以获得实用的蚀速和良好的腐蚀表面。

InP used to be etched with strongly corrosive chlorine based gases. High temperature was also needed. It is harmful to device, as well as processes and equipment. Comprehensive study has been taken for reactive ion etching of InP with  $\text{CH}_4/\text{H}_2$ . Main factor that made great effect on etching was gas composition. Ratio between  $\text{CH}_4$  and  $\text{H}_2$  affected the etch rate evidently. InP was etched slowly in pure  $\text{H}_2$ . Etch rate increased rapidly with adding of  $\text{CH}_4$ , showing quantity of reactive species was primary factor. Etch rate decreased after reaching the peak rate. It was caused by deposits of polymer and carbon, which inhibited etching process. Etching pressure also made effect on the etch rate. Similar trend was observed in low pressure, but etch rate decreased, owing to less reactive species. Gas flow rate and RF power would affect the etch rate in varying degrees. Etching profile and topography had intimate relation with etching processes. Deposition accompanied the whole process, over-etched sidewall appeared in case with high carbon contain. With high bombardment energy of ions in low pressure, vertical sidewall could be obtained.

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### 反应离子刻蚀中断面轮廓的形成



## Formation of Profile in Reactive Ion Etching

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从实验结果和理论分析可得到这样的认识: 反应离子刻蚀过程中存在腐蚀和淀积的两个相反过程。腐蚀断面轮廓取决于淀积/吸附和溅射/解附两个过程之间的对比程度、钝化层的抗腐蚀能力, 以及离子轰击的效果。“腐蚀”和“钝化”两个过程是连续并行的, 而钝化层的厚度在不同情况下起到不同程度的作用。

根据腐蚀/钝化的不同对比, 会形成五种不同的断面结果:

- 1) 钻蚀——没有侧墙保护, 强烈的各向同性腐蚀。
  - 2) 内倾——开始时形成的淀积层较薄, 不足以阻挡钻蚀, 但达到足够厚度就可以抑制横向侵蚀。逐渐形成侧墙向里倾斜的倒锥状。
  - 3) 垂直——腐蚀/淀积对比恰到好处, 侧墙有足够的保护, 纵向由于离子的清除作用而不断得到腐蚀。
  - 4) 外倾——侧墙上的淀积物不仅能防止游离基的穿透, 而且其厚度还直接影响到断面的轮廓。在离子轰击达不到的侧墙根处钝化层底下的材料不受腐蚀, 因而随着反应过程的进展, 墙根不断向外扩张, 最后形成侧墙向外倾斜的正台面断面。
  - 5) 抗蚀——产生严重的淀积物, 足以阻止整个腐蚀反应。
- 通过改变腐蚀气体及工艺参数以调节淀积物的形成, 可以得到不同的腐蚀断面轮廓。

It is known from theoretical analyse and experimental practice: The two diverse processes of etching and deposition exist simultaneously in reactive ion etching. Etching profile is depend on the contrast between deposition / adsorption and sputtering / desorption, resistance ability of passivation layer and the effect of ion bombardment. 'Etching' and 'passivation' appear parallely and continuously. Thickness of the passivation layer would play different roles in various circumstances. According to different contrasts of etching and passivation, five different profiles would appear:

- 1) Undercut—No sidewall protection, serious isotropic etching.
  - 2) Inward—Thin deposit layer is formed at the beginning which is unable to protect the sidewall from etching. Lateral etching is restrained as the deposit becomes thicker. An upside down cone like shape is formed.
  - 3) Vertical—With appropriate contrast of etching and deposition, sidewall gets enough protection from etching, and etching in vertical direction proceeds owing to the clearing effect of ions.
  - 4) Outward—Thickness of passivation layer affects directly to the profile formation. At the base of sidewall the area under the passivation layer does not etch, it extends and forms a cone like shape progressively.
  - 5) Resistant—Serious deposits are formed which prohibit any etching reaction.
- By changing gas composition and process parameters, various profiles can be

obtained.

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## InGaAsP 微细结构的反应离子刻蚀

### Reactive Ion Etching of Microstructure for InGaAsP

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在器件制作工艺中，干法腐蚀比惯用的湿法腐蚀具有更多的优越性。对于 InGaAsP 的四元系材料，由于多种元素的相互制约，所采用的氯基气体均不令人满意。采用  $\text{CH}_4 + \text{H}_2 + \text{Ar}$  气体对 InGaAsP 进行反应离子刻蚀可得到光滑表面的各向异性腐蚀，并研究了工艺参数和气体成份的作用，从而作出微细结构。对四元材料的腐蚀，必须采用对各元素均有腐蚀反应的腐蚀气体。在实验过程中发现，InP 和 GaAs 在纯  $\text{H}_2$  下的蚀速极低。随着  $\text{CH}_4$  的加入，蚀速线性增大。蚀速与气体成份的关系对这三种材料有着相似的变化趋势。蚀速随  $\text{CH}_4$  含量的增多而线性上升，有一峰值，然后下降。由于所生成的淀积物的不同程度的作用，在不同工艺条件下所形成的腐蚀断面不同。在高气压下出现向里凹的内倾型断面，在高  $\text{CH}_4$  含量时为外倾型，而且底部有圆弧形。Ar 的加入有利于垂直侧墙的刻蚀。这是由于高能量 Ar 离子的垂直轰击清除了水平表面的淀积物，而侧墙上仍保留着起保护作用的淀积物。腐蚀过程中掩模的损耗极小。采用光刻胶可以得到极大的腐蚀选择比。结合全息光刻技术，我们作出了 InGaAsP 的微型光栅结构。

Owing to conditioning each other of multi-elements, reactive ion etching of quardry InGaAsP with chlorine based gases had never been succeeded satisfactorily. Etching of InGaAs with  $\text{CH}_4 / \text{H}_2 / \text{Ar}$  resulted in smooth surface and anisotropic etching. In etching of quardry materials, gases which react with all the four elements must be used. It had been observed that etch rate was extremely small for InP and GaAs in pure  $\text{H}_2$  etching. Etch rate increased linearly with adding of  $\text{CH}_4$ . Relations between etch rate and gas composition for the three materials showed with similar trends. Etch rate increased with  $\text{CH}_4$  at the beginning, then decreased passing a maximum. Etching profiles differed with various processes owing to varying degrees of deposits produced. Inwards inclined sidewall appeared with high pressure. Outward sloped sidewall was observed with high  $\text{CH}_4$  contain. Ar was preferrable for vertical etching. Because high energy bombardment of Ar ions cleared the deposits on the surface, while the deposits on sidewall which acted as a passivation layer remained intact. Good selective etching was obtained with resist. Grating of InGaAsP had been fabricated.

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## GaAs 深孔的反应离子刻蚀

### Reactive Ion Etching of GaAs Via Holes

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GaAs 的几十甚至上百个微米的深腐蚀工作是一个比较棘手的问题。在工作实践中按照自己的实验经验探索了一种刻蚀深层 GaAs 的方法。本文介绍  $\text{SiCl}_4\text{Cl}_2/\text{Ar}$  气混合气对 GaAs 作深腐蚀的工作。在 III-V 族材料的反应离子腐蚀中，由于 III 族和 V 族元素的化学特性有较大差异，反应生成物不一定是挥发性的化合物，因而经常伴有淀积物，阻碍腐蚀反应。因此腐蚀过程中蚀速往往随时间的加长而下降。在设计 GaAs 深腐蚀的气体系统时必须考虑高蚀速、表面净化和清除反应淀积物等三个要素。选择  $\text{Cl}_2$  作为高蚀速气体，也要加以控制。 $\text{SiCl}_4$  对纯 GaAs 外，对 GaAlAs 及 GaAs 的氧化层都有腐蚀作用。Ar 气一方面起稀释作用，同时对改善腐蚀的垂直性有好处。还能对腐蚀过程起到清除反应淀积物的作用。在选择刻蚀方案的同时，也要选择好刻蚀的掩模材料， $\text{SiO}_2$  和光刻胶都可以作为 GaAs 的掩模材料。利用  $\text{SiCl}_4/\text{Cl}_2/\text{Ar}$  混合气，在适当的工艺条件下，可一次对 GaAs 进行深腐蚀。腐蚀表面光滑，蚀速大于  $2\mu\text{m}/\text{min}$ ，深度可达  $80\mu\text{m}$  以上。

It is a troublesome issue in deep etching of GaAs.  $\text{SiCl}_4/\text{Cl}_2/\text{Ar}$  gas system is introduced for GaAs deep etching. Because of the great differences between the chemical characteristics of the group III and group V elements, products of reactions are not always volatile. Depositions are always accompanied and inhibit the etching reaction. Consequently, etch rate decreases with time. In designing a system for deep etching of GaAs, high etch rate, surface cleanliness, and clearing of deposition must be taken into account.  $\text{Cl}_2$  was chosen as high rate etcher,  $\text{SiCl}_4$  can etch not only GaAs but also GaAlAs and oxide of GaAs. Ar would be a diluter, it is good at the same time for vertical etching, it also acts for deposits clearing. Masking material is important in etching process.  $\text{SiO}_2$  and resists can be used as mask. With appropriate condition, GaAs wafers with  $80\mu\text{m}$  in depth can be etched in a single step with an etch rate greater than  $2\mu\text{m}/\text{min}$  and a smooth surface.

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## 薄层 III ~ V 族半导体材料的精细干法腐蚀

### Dry Etching for Thin Layers of III-V Compounds

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以往对Ⅲ~V族材料的干法腐蚀,均采用氯基气体。对几百埃的极薄层和极微细的刻蚀都极难于控制。本文介绍用  $\text{CH}_4/\text{H}_2$  混合气系统对 GaAs 和 InGaAsP 的极微细腐蚀。用  $\text{CH}_4/\text{H}_2$  对 InP 材料进行腐蚀实验,得到很好的结果。用  $\text{CH}_4/\text{H}_2$  腐蚀 GaAs 可以得到光洁的腐蚀表面,图形整齐清晰,蚀速可控在几十埃的量级。对 InP、InGaAsP 和 GaAs 的蚀速的影响随  $\text{CH}_4$  含量的变化,有相似的变化趋势。在纯  $\text{H}_2$  中蚀速极低,加入  $\text{CH}_4$  后,蚀速随着  $\text{CH}_4$  在混合气中的含量的增加而增加。 $\text{CH}_4$  含量分别为气体总流量的 20% 和 35% 时,对 GaAs 和 InGaAsP 达到最大蚀速。随后,蚀速随  $\text{CH}_4$  的增加而下降。这是由于反应生成某种有机聚合物,淀积在材料表面,妨碍腐蚀作用。 $\text{CH}_4/\text{H}_2$  中掺入氩气,可更便于垂直腐蚀的控制。曾经在 CaAs MESFET 的制作中,用干法腐蚀方法来调整注入层的深度。对 GaAs 和 InGaAsP 制作了二级和一级光栅,其线度分别为 230nm 和 115nm。条纹侧墙垂直,深度大,制作分布反馈激光器,得到较好的耦合系数。

Chlorin based gases used to be etch gas for III-V compounds. It is not easy to control for thin layer and fine structure etching down to several hundred Angstroms. Precise etching of GaAs and InGaAsP can be achieved with  $\text{CH}_4/\text{H}_2$  mixed gas. Similar trends in relation of etch rate and  $\text{CH}_4$  contain appear for InP, InGaAsP and GaAs. Etch rate is very low with pure  $\text{H}_2$ .  $\text{CH}_4$  in the etch gas will increase the etch rates which reach their maximum with 20% and 35% of  $\text{CH}_4$  in the over-all flow rate for GaAs and InGaAsP respectively. The etch rates decrease due to formation of polymers which prohibit the etch. Adding of argon into the etch gas makes control of vertical etching easier. Thickness of implanted layer was adjusted by fine etching had been used in GaAs MESFET fabrication. Grating of GaAs and InGaAsP which had a line width of 230nm and 115nm respectively were achieved. Better coupling coefficient of DFB laser were obtained with vertical sidewall and deeper grooves.

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### 氩离子在反应离子腐蚀Ⅲ-V族材料中的作用

#### The Roles of Argon Ion in RIE of III-V Compounds

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对Ⅲ-V族材料来说,反应离子腐蚀技术中, $\text{Ar}^+$ 离子的作用更具有重要的实用意义。

1.  $\text{Ar}^+$ 离子抑制晶向腐蚀现象多数Ⅲ-V族材料的干法腐蚀都伴有晶向特征。例如在  $\text{SiCl}_4$  反应离子腐蚀 GaAs 沿 $[0\bar{1}1]$ 方向的断面上, 腐蚀面向外倾斜, 形成与(100)衬底倾角为  $55^\circ$  的外倾坡面。这是 $\{111\}$ 晶面。在  $\text{SiCl}_4$  中加入氩气, 可更大地增加离子轰击能量, 增加了 $\{111\}$ 面的损伤, 加速沿这个方向的蚀速, 有效地消除晶向现象。

2.  $\text{Ar}^+$ 离子调节钝化阻挡层由于Ⅲ族元素和V族元素的化学特性差别较大, 腐蚀反应生成物的汽化点也有较大的距离, 一般情况下都会形成不同程度的淀积物。腐蚀气体的成份、工作气压以及功率密度等都会直接影响淀积物的生长速率。但是以调节这些工艺参数来实现轮廓控制, 往往是难以掌握的, 腐蚀气体中加入氩气可以得到更好的效果。

3.  $\text{Ar}^+$ 离子有效地清除非挥发性微粒淀积物在某些腐蚀反应中会产生微粒淀积物。这种非连续性的淀积物会斑斑点点地散布在样品表面上, 形成颗粒状的微掩模, 极大地影响到腐蚀表面的光洁度, 严重情况下会形成“草”状腐蚀表面。在腐蚀气体中加入氩气, 可以有效地减少“草”的生长。这是由于  $\text{Ar}^+$ 离子的轰击作用溅射掉作为长“草”的根源的微粒淀积物。

Playing the role of Ar ion in RIE of Ⅲ-V compounds are more significant.

1. Ar ion restrains crystallographic etching phenomena Etching of Ⅲ-V compounds would accompany with crystallographic characteristic, such as in etching GaAs with  $\text{SiCl}_4$ . Bombardment energy of ions will increase when Ar is added into  $\text{SiCl}_4$ . Damage on plane  $\{111\}$  will be enhanced, etch rate in this direction increases and crystallographic etching is restrained.

2. Ar ion regulate the passivation layer Deposits always accompany in etching of Ⅲ-V compounds owing to great difference of chemical characteristic of the two elements. Etching profiles can be changed through adjusting of etching parameters. Better effects and easier control can be obtained by adding Ar to the gas

3. Ar ion clear the non-volatile micro-deposits effectively Micro-deposits would appear in some cases, and form particle-like mask on the surface. Etched surface becomes rough and 'grass' will form with the micro-mask. Micro-mask will be sputtered by Ar ion and the 'grass' will be uprooted.

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## GaAs 精细刻蚀的断面轮廓控制

### Profile Control in Micro-Etching of GaAs

李建中

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对于采用反应离子刻蚀技术制作 GaAs 精细结构中, 在断面轮廓的形成问题上我们在

两个方面做了研究:

定向刻蚀中性的游离基是主要的腐蚀粒子,而离子在腐蚀方向性上起着决定性的作用。侧墙上由于淀积层不受离子轰击而起到对侧墙的钝化保护作用,从而实现腐蚀的方向性。 $\text{Cl}_2$ 对GaAs有强烈的反应,蚀速很高,腐蚀表面粗糙,采用 $\text{CF}_3\text{Br}/\text{Cl}_2$ 和 $\text{SiF}_4/\text{Cl}_2$ ,腐蚀表面也显得光滑些,但对断面控制仍难以掌握。在 $\text{SiF}_4/\text{CCl}_4$ 和 $\text{CF}_4/\text{CCl}_4$ 系统中发现,虽然可以得到很好的垂直侧墙,但任由改变腐蚀参数,都不能消除反应过程所产生的淀积物。采用含 $\text{SiCl}_4$ 可以恰到好处地克服 $\text{Cl}_2$ 的猛烈腐蚀反应和 $\text{CCl}_4$ 的浓厚淀积物。在反应过程中形成适中的钝化层,侧墙得到足够的保护,而且腐蚀表面光洁平整。可制作毫微米级的精细结构。

晶向腐蚀 用 $\text{SiCl}_4$ 的反应离子刻蚀,首次得到了GaAs晶向腐蚀效果。在一定的腐蚀条件下,GaAs的各个晶向有不等的蚀速,从而形成带有晶向特征的断面。在 $[011]$ 方向上显示出 $\{111\}$ 晶面,形成外倾斜面,而在 $[0\bar{1}1]$ 方向上则出现向里的凹蚀。按 $[0\bar{1}1]$ 取向,则可制作倒台面结构。用并排的细线按 $[011]$ 取向,利用 $\{111\}$ 面的晶面结构,可制作锯齿形光栅结构。

Two kinds of etching profile control have been carried on.

Orientation etching Radicals are main etching species, while ions play a decisive role in etching direction. Sidewall kept intact owing to the passivation of the deposits, and vertical etching achieved.  $\text{Cl}_2$  reacts strongly with GaAs, with very high etch rate and rough etched surface.  $\text{CF}_3\text{Br}/\text{Cl}_2$  and  $\text{SiF}_4/\text{Cl}_2$  etched smoothly, but etching profile still was out of control. Very good vertical etching was achieved with  $\text{SiF}_4/\text{CCl}_4$  and  $\text{CF}_4/\text{CCl}_4$ , but deposits could not be eliminated. Strong etching of  $\text{Cl}_2$  and deposit with  $\text{CCl}_4$  could be avoided when etch with  $\text{SiCl}_4$ . Vertical sidewall was achieved with smooth surface, and nanometer structures were fabricated.

Crystallographic etching Crystallographic etching was observed for the first time with  $\text{SiCl}_4$  RIE. Under certain condition, etch rates in different directions differed, achieving in profile with crystallographic characteristic. Plane of  $\{111\}$  was delineated in the direction of  $[011]$ , achieving in outward sloped sidewall, while inward etching was found in the direction of  $[0\bar{1}1]$ . Specific structures could be made with crystallographic etching.

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### KKH 溶液对 InGaAsP-InP 材料的选择腐蚀特性

#### The Selective Etching Characteristics of KKH Solution for InGaAsP-InP Materials

吕章德 徐少华 鄢祥生

(中国科学院上海冶金研究所)

本文介绍了 KOH 和  $K_3Fe(CN)_6$  混合溶液 (KKH) 对 InGaAsP-InP 体系材料的选择腐蚀特性, 测定了 (100) InP 和不同禁带宽度的  $In_xGa_{1-x}AsyP_{1-y}$  材料在 KKH 腐蚀液中的腐蚀速率; 研究了  $\lambda = 1.3\mu m$  的  $In_xGa_{1-x}AsyP_{1-y}$  材料和 InP 材料的腐蚀速率与温度关系。结果表明, KKH 腐蚀液对  $In_xGa_{1-x}AsyP_{1-y}$ -InP 异质结材料具有选择腐蚀的特性。随着 y 值增加, 选择性亦增加。腐蚀速率与温度的关系进一步表明,  $In_xGa_{1-x}AsyP_{1-y}$  的腐蚀属扩散过程控制, 而 InP 的 KKH 溶液腐蚀是反应速率控制, 它们的活化能分别为 12560.4J/mol 和 41868J/mol。

The selective etching characteristics of KKH for  $In_xGa_{1-x}AsyP_{1-y}$ -InP materials are reported in details. The etching rates of (100)InP and  $In_xGa_{1-x}AsyP_{1-y}$  in KKH solution are studied. The results indicate that KKH etchant is useful for the selective etching of  $In_xGa_{1-x}AsyP_{1-y}$ -InP materials. The selectivity of KKH increases with enlarging the y value of semiconductor compound. The etching of  $In_xGa_{1-x}AsyP_{1-y}$  and InP in KKH are diffusion-controlled and a reaction-rate-limited process, respectively. The energy of activation are also calculated.

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### 有机金属化学气相沉积

#### Metalorganic Chemical Vapour Deposition (MOCVD)

邬祥生

(中国科学院上海冶金研究所)

本文概述了当前 MOCVD 的研究状况, 介绍了它的发展历史, MOCVD 装置系统, 包括源及气路、反应室、加热和测温控制系统、排气及废气系统、检测和报警系统、反应机理, 还介绍了 MOCVD 的应用和发展动向。文中指出, MOCVD 技术已日益成为普遍采用的一种生产和研究手段, 呼吁我国重视这门技术。

另外, 还对用 Razeghi 描述气体在反应室情况的概念作了阐述, 有助于反应室设计参考。

In this letter, the MOCVD process is described and the history of the technique, equipments, some of the materials and devices applications and recent developments are reviewed.

本文发表在《上海半导体》, 第 3 期, 1990 年

## 掺铒[Er]光纤光放大器的理论分析

### Theoretical Analysis of Er Doped Fibre—Optic Optical Amplifier

曾庆济 杜 敏

(上海交通大学)

已经证明, 稀土元素铒[Er]掺杂的光纤放大器, 特别易于与现有长波长光纤通信系统匹配和兼容, 可在  $1.54\mu\text{m}$  窗口获得高效率的光放大增益 (3dB 带宽  $> 300\text{GHz}$ ) 和低噪声性质。现有文献对其试验结果已作过许多阶段性报道和综述, 但理论分析尚欠缺。本文基于众多报道的实验结果和数据曲线, 从理论上详细分析和讨论了这类放大器的工作原理, 并对其参数性能作了实例计算, 计算是在计算机上完成。

It has been proved that the rare-earth element Er doped fibreoptic amplifier is pretty fit for the current long wavelength fibreoptic communication system. An high efficient optical amplifying gain(3dB bandwidth  $> 300\text{GHz}$ ) and low noise can be obtained at the  $1.54\mu\text{m}$  window. Up to date, many literatures have reported testing results by stages, but the theoretical analysis has been barely seen. In this paper we calculate and discuss the principle of this kind of amplifier in theory and in detail, basing on the reported experimental results. An example of calculation is given. All the calculations were done on a computer.

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## 光纤放大器分析的线性模型法

### A Linear Model Method Analyzing Optical Fibre Amplifier

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(上海交通大学)

增益分析和测量是光纤放大器研究中最重要二个基本问题。迄今文献报导中提出的测量计算方法大多是针对具体的实验而不是从整个放大器系统角度来考虑以建立一个普适的测量方法。本文基于能量守恒原理, 提出了一种新的分析光纤放大器的线性模型法, 即输出—输入功率图法。将光放大过程中的非线性变换视作等效的输入激励, 化复杂的非线性转换过程为简单的线性光传输问题。通过光放大器的泵浦工作点, 变换效率和变换阈值等概念导出了便于测量使用的计算斯托克斯光放大器增益的计算公式, 并给出了光放大器的线性模型框图。

Gain analysis and measurement are two of the most important fundamental problems



in the study of optical fibre amplifier. Up to date, many literatures have reported methods used in testing and calculation have been produced mainly for specific experiments, rather than considered for general amplifier systems. In this paper, a new linear model method, i.e. out put-input power diagram method, analyzing optical fibre amplifier is proposed based on the energy conservation principle. By treating the nonlinear transformation effect in the light amplification process as an equivalent input excitation, the complex nonlinear process is simplified as a linear transmission problem. In terms of the concepts of pump bias point in optical amplifier, transformation efficiency and threshold, a simple formula which is convenient to use in testing and calculation of stokes fibre amplifier is derived. In addition, a linear model block diagram is given.

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**严格无阻塞 PLZT 空分矩阵光开关**  
**Strict Nonblocking PLZT Space-Division**  
**Matrix Optical Switch**  
曾庆济 段耀明 叶爱伦  
(上海交通大学)

本文报道了一种应用 PLZT 具光门构成的严格无阻塞矩阵光开关。它具有双向广播和点一点通信功能,并具有 600nm 的 3dB 带宽。对宽带 HDTV 空分交换/分配系统有巨大的应用潜力。

This paper reports a strict nonblocking space-division matrix switch using PLZT optical gate. It has bidirectional broadcasting and point-point communication functions, and possesses a 3dB bandwidth of 600nm. It is promising in the application of wideband HDTV spacedivision switching / distributing system.

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**新型偏振无关 PLZT 光开关**  
**A Novel Polarization Independent**  
**PLZT Optical Switch**  
段耀明 曾庆济  
(上海交通大学)

由于在目前光开关中占主导地位的  $\text{LiNbO}_3$  波导光开关因其偏振敏感性, 只对单模光纤系统工作有效及光纤波导耦合困难等缺陷, 限制了它的应用。利用 PLZT 铁电陶瓷制成的电光开关具有良好的开关性能和巨大的带宽特性。目前, PLZT 光开关主要存在着工作电压高及 3dB 偏振损耗等问题。本文针对这两个问题提出了一种新型结构的 PLZT 光开关, 它消除了 3dB 偏振损耗, 并有效地降低了半波电压。

As the extensively studied  $\text{LiNbO}_3$  waveguide switch has the disadvantages of polarization sensitivity and efficient operation only with single-mode fibre-optic systems, its application are limited. The optical switch using PLZT ceramic has good switching performance and huge bandwidth. At present, the higher halfwave voltage and 3dB inherent polarization loss are the major problems of PLZT optical switches. This paper propose a novel polarization Independent PLZT optical switch. It both eliminates the 3dB polarization loss and reduces the halfwave voltage effectively.

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## 宽谱 PLZT 光开关

### Wide Spectrum PLZT Optical Switch

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(上海交通大学)

本文报道了一个宽谱 PLZT 光开关。该光开关具有高速开关响应和宽广平坦的光谱特性。在 700nm 的波长范围内均具有良好的开关性能。在该范围内, 其消光比大于 35dB, 插入损耗小于 8dB。该结果系首次报道。2.85 $\mu\text{s}$  的接通响应时间和 0.27 $\mu\text{s}$  的断开响应时间使得它十分适合于要求开关速度仅在  $\mu\text{s}$  级以下的诸如高清晰度电视 (HDTV) 信号的交换或分配的空分宽带交换网中应用。

This paper describes a wide spectrum PLZT optical switch. This switch has a high switching speed and huge flat wavelength characteristics. Among the range of 700nm, it has a good switching performance that the extinction ratio is great than 35dB, and insertion loss is less than 8dB. This result has been reported for the first time. Its turn-on response time of 2.85 $\mu\text{s}$  and turn-off response time of 0.27 $\mu\text{s}$  makes it fit for the application in the space-division wideband switching networks which have the requirement of switching response time under  $\mu\text{s}$ , such as the switching or distributing of HDTV signals.

本文发表在《第五届全国光纤通信学术会议论文集》

## ZnSe—ZnS 应变超晶格的光学特性

### Optical Properties of

### ZnSe—ZnS Strained Superlattices

范希武 范广涵 申德振 关郑平 江凤益 张吉英

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用有机金属化学气相沉淀 (MOCVD) 法分别在 GaAs 和  $\text{CaF}_2$  衬底上生长出了高质量的 ZnSe—ZnS 应变超晶格, 最小的阱宽达 2nm. 在 X 射线的衍射中观察到了多级次的卫星峰, 表明了超晶格结构的存在, 在 77K 下研究了 ZnSe—ZnS 应变超晶格的激子发光特性, 对通常只有一个发光峰的起因归结为激子与电子的散射, 对观察到的两个发光峰归结为  $n=1, 2$  的重空穴激子发光, 在 77K 下 ZnSe—ZnS / GaAs 超晶格中观察到了明显的光双稳现象, 分析结果表明, 在 ZnSe—ZnS 超晶格的两表面能够形成一个简单的 F—P 腔, 其主要机理是激子的饱和吸收引起的折射率变化。

Good quality ZnSe—ZnS strained—layer superlattices (SLS<sub>s</sub>) were grown by atmospheric pressure (AP) metalorganic chemical vapor deposition (MOCVD) and identified by X—ray diffraction and photoluminescence (PL) measurements. The PL bands in the SLS were studied and ascribed to transition of subband heavy—hole excitons. The excitonic dispersive optical bistability with ns responses time was measured in ZnSe—ZnS SLS and its origin was attributed to the simple F—P cavity from the faces of front and back of ZnSe—ZnS SLS and the change of refractive index due to the excitonic saturating absorption.

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## 常压 MOCVD 透明衬底 $\text{CaF}_2$ 上

### 生长 $\text{ZnSe}_{1-x}\text{S}_x$ 外延膜

### Growth of $\text{ZnSe}_{1-x}\text{S}_x$

### Epilayers on Transparent Substrate $\text{CaF}_2$

### by MOCVD at Atmospheric Pressure

关郑平 范广涵 宋世惠 范希武

(中国科学院长春物理研究所)

利用 MOCVD 系统在透明衬底  $\text{CaF}_2$  上生长了高质量  $\text{ZnS}_{1-x}\text{S}_x$  单晶。通过 PL 光谱、X—ray 衍射和透射光谱分析了外延膜的质量。利用应力效应, 解释了在相同生长条件下  $\text{ZnSe}_{1-x}\text{S}_x$  /  $\text{CaF}_2$  和  $\text{ZnSe}_{1-x}\text{S}_x$  / GaAs 外延膜中组分的不同和失配位错的差别。作者把它们归结为, 减少应变能  $\text{CaF}_2$  衬底能够在相同条件下俘获更多的硫 (S) 原子。

Direct band gap ternary alloys  $\text{ZnSe}_{1-x}\text{S}_x$  epilayers on  $\text{CaF}_2(111)$  transparent substrate have been prepared by MOCVD at atmospheric pressure. The double crystal X-ray diffraction pattern, PL spectra and the absorption spectra showed the epilayers with higher quality. Using the effect of strain we explained the alloys compositional disparity and the dislocation defect density about the  $\text{ZnSe}_{1-x}\text{S}_x$  epilayer on  $\text{GaF}_2(111)$  substrate and  $\text{GaAs}(100)$  substrate under the same growth condition.

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### **$\text{ZnSe}_{1-x}\text{S}_x$ -ZnSe 应变超晶格 结构光致发光的线型研究**

#### **Study of Excitonic Lineshape of $\text{ZnSe}_{1-x}\text{S}_x$ -ZnSe Strained-Layer Superlattices**

关郑平 范广涵 宋世惠 范希武  
(中国科学院长春物理研究所)

本文研究了  $\text{ZnSe}_{1-x}\text{S}_x$ -ZnSe 应变超晶格结构在 77K 时，光致发光的线型随激发光密度，势阱涨落，势垒高度的涨落及各层厚度对超晶格发光峰  $E_s$  的影响，并利用 Kronig-Penney 模型计算了  $n=1$  的激子峰值能量与势阱宽度、势垒高度涨落的关系。同时，首次从实验上分析了 77 ~ 250K 温度范围内  $\text{ZnSe}_{1-x}\text{S}_x$ -ZnSe 应变超晶格激子发光的线型与各参量的密切关系。

Photoluminescence (PL) technique are used to diagnose the quality of  $\text{ZnSe}_{1-x}\text{S}_x$ -ZnSe SLS. The influence on the fluorescence spectra of SLS due to excitation densities, fluctuation of wells thickness and barriers height, acts of mixcrystal in interface are discussed. The relation of the fluctuation of wells thickness and barriers height to the broadening of  $n=1$  excitonic energies are calculated using Kronig-Penney Model. We analyse, in first time, the relation of the excitonic lineshape to each parameter of growth in the temperature range from 77 to 250K for  $\text{ZnSe}_{1-x}\text{S}_x$ -ZnSe SLS.

本文发表在“第五届全国凝聚态光学性质会议”，延吉，1990 年

### **ZnSe-ZnS 超晶格中的激子束缚能和光致发光 Photoluminescence and Binding Energies of Wannier**

## Excitons in ZnSe-ZnS Superlattices

关郑平 范希武 范广涵

(中国科学院长春物理研究所)

本文研究了在 77~250K 温度范围内和不同的激发密度下 ZnSe-ZnS 超晶格的发光性质, 通过 Kronig-Penney 模型应力理论及实验数据, 首次计算了 ZnSe-ZnS 超晶格的激子束缚能, 得到了势阱宽度在 9~20nm 的范围内 ZnSe 层的激子束缚能增加了一倍, 变化范围为 30~45MeV。此结果表明, 在 ZnSe-ZnS 超晶格中可望获得有效的激子发光和光学非线性。

In this paper, we explain the origin of the PL peak in ZnSe-Zns SLS at 77-250K by change the excitation density and tempertature, we ascribed it to the excitonelectron collision and obtain the excitonic energy  $E_0$  in the ground state. Then we calculate the electron and hole energy levels  $E_e$   $E_h$  respectively in the ZnSe well using the Kronig-Penney Model. Because of a compressive strain  $e''\text{ZnSe} > 0$  for ZnSe layer, the energy shift  $\Delta E_1(h)$  is positive and the band gap increase, while a tensile strain  $e''\text{ZnS} < 0$  for ZnS layer, the energy shift  $\Delta E_2(h)$  is negative and decrease the barrier. The effective band gap of ZnSe well is  $E_g^* = E_g + E_e + E_h + \Delta E_1(h)$ . At last we calculate the binding energies of ZnSe-ZnS SLS. The binding energies increase from 30 to 45eV, with the thickness of ZnSe well changing from 9 to 20nm.

本文发表在“第七届全国半导体物理会议”, 上海, 1989 年

### 常压 MOCVD 法在透明衬底 $\text{CaF}_2$ 上 生长高质量 ZnSe 单晶薄膜

Growth of High-Quality ZnSe Single  
Crystal Epilayers on Transparent Substrate  
 $\text{CaF}_2$  by MOCVD at Atmospheric Pressure

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本实验利用  $\text{CaF}_2$  的自然解理面 (111) 表面, 经过适当的清洗, 在 MOCVD 系统中衬底温度为 300℃ 下外延生长出表面具有明亮的黄色透明镜面 ZnSe 单晶薄膜。通过 X 射线衍射、PL 光谱分析研究了外延层的形貌结构和光电特性, 证明外延层是高质量的单晶 ZnSe 膜。X 射线衍射表明, 外延层为 (111) 取向的单晶; 而在 X 双晶衍射的回摆曲线中, 其 ZnSe 衍射峰仅为 0.21 度, 说明尽管与衬底的失配度为 3.6%, 而结晶非常好。在 PL 光谱中有很强的蓝色发光, 与自由激子有关的  $E_s$  峰半宽度 (77K) 仅为 30MeV, 在

长波段没有发现杂质中心的发射，这点对于进一步制备激子型 ZnSe 双稳器件尤为重要。

High quality ZnSe epilayers on  $\text{CaF}_2(111)$  transparent substrate have been successfully fabricated for the first time by atmospheric pressure MOCVD. The double crystal X-ray diffraction pattern (111) shows a little shift of ZnSe diffraction peak toward low diffraction angle and the full width at half maximum (FWHM) of diffraction peak value from its (111) face is about  $0.21^\circ$ . The optical and electrical characteristics of ZnSe epilayers were measured by photoluminescence (PL), SEM and Van der pouw method, the epilayers exhibit high crystallographic quality and reveal even mirror surface. All epilayers present high resistivities up to  $10^7 \Omega \cdot \text{cm}$ . Based on analyses regarding the energy shift of the luminescence line, it has been found that a compressive stress in the epilayer sides of these heterostructures, this is consistent with the stresses predicted for a lattice mismatch between the ZnSe epilayer and the  $\text{CaF}_2$  substrate.

本文发表在“第八届美国晶体生长会议”，1990 年

## ZnSe-ZnS 应变超晶格的激子发射和吸收

### Excitonic Emission and Absorption of ZnSe-ZnS Strained Layer Superlattices

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用常压有机金属化学汽相沉淀 (MOCVD) 法，在 GaAs 衬底的 (100) 方向和  $\text{CaF}_2$  衬底的 (111) 方向上生长了 ZnSe-ZnS 应变超晶格。在 77K 下的 ZnSe-ZnS 应变超晶格的发光光谱中，观察到了两个发光峰，并且在室温下观察到 4 个吸收峰。我们根据 LCAO 理论、应变理论和 K-P 模型计算了 ZnSe-ZnS 超晶格的子能级，比较理论计算结果与实验结果，获得的两个发光峰和 4 个吸收峰能够根据  $n=1, 2$  的子能级轻重空穴激子跃迁来解释，这些结果表明生长的 ZnSe-ZnS 应变超晶格具有较高的质量，为实现低阈值，快速激子型光双稳器件提供了可能性。

ZnSe-ZnS strained layer superlattice (SLS) on (100) GaAs and (111)  $\text{CaF}_2$  substrates was grown by atmospheric pressure (AP) MOCVD. The photoluminescence spectrum at 77K in ZnSe-ZnS SLS usually has only one near band edge emission band  $E_s$ , which can be attributed to free exciton recombination following scattering from free electrons in the conduction band. Two emission bands in the PL Spectra at 77K and four absorption bands in the absorption spectra at RT for a selected ZnSe-ZnS SLS were observed for the first

time. Using the LCAO theory, the theories of the stress induced energy band structure and the Kronig-penney band model, the subband levels of mentioned above can be explained by the  $n=1, 2$  subband heavy-hole and light-hole excitons calculated.

本文发表在“半导体及相关材料光谱及光电现象联合讨论会”，上海，1990年

### 关于 ZnSe / ZnS 超晶格的 P 型传导机理的探讨

#### Approach to the Conduction Mechanism of Znse / ZnS Superlattices on Semiinsulating Substrate GaAs(100)

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我们对过去生长的样品 87039SI ZnSe / ZnS 超晶格进行了变温 Hall 测量，发现样品呈 P 型导电特性。其载流子浓度高达  $10^{18}\text{cm}^{-3}$ ，迁移率为  $30\text{cm}^2/\text{V} \cdot \text{S}$ 。对这种反型机理，本文进行了讨论。我们认为，当 ZnSe、ZnS 层厚大于其临界厚度时，ZnSe / ZnS 界面出现悬键；该悬键引起的受主能级处于 ZnS 层靠近界面附近。它的能级比 ZnSe 价带能级低。这样能较好地解释 87039SI 号样品的载流子浓度基本不随温度变化这一现象。

With the different temperature from 77K to 300K, We obtained the electrical parameters of 87039SI ZnSe—ZnS superlattices by the Van de pauw Hall measure ment. The sample was verified to be P—type semiconductor material with high hole carrier concentration  $10^{18}\text{cm}^{-3}$  and the loww drift—mobility  $30\text{cm}^2/\text{V} \cdot \text{S}$ . When the thicknesses off ZnSe and ZnS layers are above the critical thickness of ZnSe—ZnS heterojunctions, the hang—bonds arise at the interfaces of ZnSe—ZnS heterojunctions. The hang—bonds can be acted as acceptors when they trapped the electrons. The acceptor level is lower than the ZnSe valence band. The model can give us a good explanation on the hole carrier concentration dependence of temperature.

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### 应变超晶格的 (110) 退沟道效应研究

#### Study of the (110) Dechannelling Effects of Strained—Layer Superlattices

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本文通过对 ZnSe/ZnS 应变超晶格的 Rutherford 背散射及其沟道效应的研究,发现应变超晶格的 (110) 反常退沟道效应并不总是显著存在。本文首次提出有效沟道宽度的概念,能较好地解释阱、垒较窄的 ZnSe/ZnS SLS 的 (110) 退沟道产额与 (100) 退沟道产额接近这一事实。

本文还通过 RBS/Channeling 实验,鉴定了用常压 MOCVD 技术生长的 ZnSe/ZnS 应变超晶格具有良好的结晶特性。

With the Rutherford Back Scattering/Channeling effects, We measured the RBS/Channeling Spectra of ZnSe/ZnS SLS on GaAs(100) substrate. The  $\langle 100 \rangle$  dechanneling yield ratio is 6%, which shows that the ZnSe/ZnS SLS grown by AP—MOCVD have good quality. The  $\langle 110 \rangle$  dechanneling yield approximately equals that of  $\langle 100 \rangle$ . For this unnormal effect, we first pointed out the model of the effective Channeling width. Using this model, We can give a good explanation on the phenomena above.

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### ZnSe/ZnS 应变超晶格的吸收光谱及其子能级计算

#### Absorption spectra and Subband Calculation of ZnSe/ZnS Strained—Layer Superlattices

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我们首次观测到在透明衬底  $\text{CaF}_2$  上生长的 ZnSe/ZnS 应变超晶格的吸收光谱。吸收光谱中出现四级明显的吸收峰。使用 LCAO 理论、应变感应能带结构理论及 Kronig—Penney 模型, 计算了 ZnSe/ZnS 应变超晶格阱中子能级 (带)。理论计算结果与实验吸收峰的位置符合得较好。四个吸收峰分别归结为  $n=1$ ,  $n=2$  重空穴激子, 及  $n=1$ ,  $n=2$  轻空穴激子的吸收。

We first observed the optical absorption spectra of ZnSe/ZnS strained—layer Superlattices grown by AP—MOCVD on substrate  $\text{CaF}_2$ . There are four peaks in these absorption spectra. Using the LCAO theory, the theories of the stress—induced energy band structure and the Kronig—Penney band model, we calculated the subbands of ZnSe wells in ZnSe/ZnS SLS. The theoretical calculation is fairly agreement with the experiment peaks. The four absorption peaks are thought to be caused by the transitions between the  $n=1,2$  electronic subbands and the  $n=1,2$  heavy, light hole's subbands, respectively.

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**在透明衬底  $\text{CaF}_2$  上常压  
MOCVD 生长  $\text{ZnSe-ZnTe}$  应变超晶格  
Growth of  $\text{ZnSe-ZnTe}$  Strained-Layer  
Superlattices by AP-MOCVD on Transparent Substrate  $\text{CaF}_2$**

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我们首次在透明衬底  $\text{CaF}_2$  上使用常压 MOCVD 技术生长了  $\text{ZnSe-ZnTe}$  应变超晶格。其生长参数控制在临界厚度之内。通过 X 射线衍射测量, 鉴别了超晶格周期结构的形成。由光致发光光谱中观测到了量子尺寸效应与应变感应能带移动效应。吸收光谱中的多级吸收峰, 表明了发生在超晶格子能带之间的多级跃迁的存在。

We first grew  $\text{ZnSe-ZnS}$  strained-Layer super lattices on transparent substrate  $\text{CaF}_2$  by atmospheric pressure metal-organic Chemical Vapour Deposition. The thicknesses of  $\text{ZnSe}$ ,  $\text{ZnTe}$  layers are controlled to be lower than the critical thickness of  $\text{ZnSe} / \text{ZnTe}$  heterojunction. There are multi-order satellites in X-ray diffraction pattern of  $\text{ZnSe} / \text{ZnTe}$  SLS, which confirms the formation of the period-structure of superlattices. We observed the quantum-size confinement effects and the effects of the stress-induced band shifts in photo-luminescence spectra. Absorption spectra with many absorption peaks show that there are multi-order transitions between the electronic subbands and the heavy, light hole's subbands of  $\text{ZnSe} / \text{ZnTe}$  SLS.

本文发表在《发光学报》, 第 1 期, 1991 年

**基于 X 射线衍射的应变超晶格的两套准超格子  
Two Quasi-Superlattices of Strained-Layer  
Superlattices for X-Ray Diffraction**

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应变超晶格的 X 射线衍射图中存在两套卫星峰。本文将超晶格解剖成两套周期结构, 一套为阱周期结构, 另一套为垒周期结构。这二套周期结构被命名为准超格子。使用这一模型及 X 射线运动学理论, 能很好地解释应变超晶格中存在两套 X 射线卫星峰。当阱、垒层厚较大时, 两套卫星峰可清楚地区分开来。

There are two sets of satellites in X-ray diffraction pattern of Strained-Layer Superlattices. Here we dissect the superlattices into: one quasi-period structure of

[well+empty lattices]adding another guasi-period structure of [empty lattices+barrier]. The guasi-structure are named as guasi-super-lattices. With this model, we can give a good explanation on the x-ray diffraction profiles of Strained-Layer Superlattices using the theories of X-ray diffraction kinematics. When the thicknesses of wells and barriers are above the X-ray diffraction guasi-critical thickness, the two sets of satellites can well be distinguished.

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### 常压 MOCVD 法生长

#### ZnSe / ZnS<sub>x</sub>Se<sub>1-x</sub> 应变层超晶格

#### On Growth of ZnSe / ZnS<sub>x</sub>Se<sub>1-x</sub> Strained-Layer Superlattices by AP-MOCVD

范广涵 关郑平 江凤益 范希武 宋士惠

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本文首次报导以常压 MOCVD 法, 用二甲基锌、硒化氢, 硫化氢为源, 在砷化镓衬底上外延生长 ZnSe-ZnS<sub>x</sub>Se<sub>1-x</sub> 应变层超晶格结构, 并讨论了气相组分对外延层组分的影响。用 X 射线衍射法和光荧光法鉴定了超晶格结构, 证明了 ZnSe-ZnS<sub>0.1</sub>Se<sub>0.9</sub>SLS 比晶格失配大的 ZnSe-ZnS SLS 有更强锐的激子发射。

ZnSe-ZnS<sub>x</sub>Se<sub>1-x</sub>SLS were grown on (100)GaAs substrates by MOCVD at atmospheric pressure for the first time, and their periodical deposition have been ascertained by observing X-ray diffraction satellites and PL measurement. As compared with the ZnSe-ZnS SLS, the ZnSe-ZnS<sub>0.1</sub>Se<sub>0.9</sub>SLS have much stronger and sharper exciton emission owing to the better lattice matching between layers.

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### MOCVD 法生长高质量硫化锌单晶薄膜

#### High Quality Zinc Sulfide Epitaxial Layers

#### Grown by Metalorganic Chemical Vapour Deposition

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以常压 MOCVD 法在 (100) GaAs、(111)GaAs、(1120)Al<sub>2</sub>O<sub>3</sub> 和 (100) Si 上生长了高质量 ZnS 单晶薄膜。反应系统和生长条件实现了优化, 有害的气相预反应被有效地抑制。以 X 射线衍射法, 光致发光、阴极射线发光和范德堡法研究了 ZnSe 外延层的光电和结晶学性质。

High quality ZnS epitaxial layers were grown on (100)GaAs, (111)GaAs, (1120)Al<sub>2</sub>O<sub>3</sub> and (100)Si by AP—MOCVD with optimization of reactor design and growth conditions. The harmful gas phase prereaction is effectively restrained. The optoelectronics and crystalline characteristics of ZnS epilayers are measured by photoluminescence, Cathodeluminesance, Van der pauw method, and X-ray diffraction.

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### ZnS<sub>x</sub>Te<sub>1-x</sub> 合金的 MOCVD 生长。

#### On the Growth of ZnSe<sub>x</sub>Te<sub>1-x</sub> Alloy by MOCVD

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ZnS<sub>x</sub>Te<sub>1-x</sub> 合金在  $x=0.63$  时, 其晶格常数与 ZnSe 相等, 且此时能带交差值仍很大, 所以 ZnSe—ZnS<sub>x</sub>Te<sub>1-x</sub> 是有希望的超晶格体系。我们用二甲基锌、二乙基碲和硫化氢为源在 GaAs (100) 上以常压 MOCVD 法生长了四个不同  $x$  值的 ZnS<sub>x</sub>Te<sub>1-x</sub> 合金, 首次证实外延层是质量较好的连续固溶单晶膜, 为生长 ZnSe—ZnS<sub>x</sub>Te<sub>1-x</sub> 超晶格准备了条件。

ZnSe—ZnS<sub>x</sub>Te<sub>1-x</sub> is a promising superlattice system, for the lattice matching ( $x=0.63$ ) and the fairly big band offset. For the first time we have grown ZnS<sub>x</sub>Te<sub>1-x</sub> alloy on GaAs(100) by AP—MOCVD using DMZ, DETe and H<sub>2</sub>S as source materials. X—ray diffraction patterns have showed the epilayers were rather good quality continuous solid solutions with various component values  $x$ .

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### ZnSe / ZnS<sub>x</sub>Se<sub>1-x</sub> 应变层超晶格的光学非线性吸收

#### Optical Nonlinear Absorption of ZnSe / ZnS<sub>x</sub>Se<sub>1-x</sub>

##### Strained—Layer Superlattices

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田 华 王寿寅 宋世惠 张吉英 杨爱华

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制备和鉴定了用常压 MOCVD 法在透明  $\text{CaF}_2(111)$  和  $\text{GaAs}(100)$  上生长的  $\text{ZnSe}/\text{ZnS}_x\text{Se}_{1-x}$  应变超晶格。首次成功地制备了超晶格的  $\text{GaAs}$  衬底的通光蚀孔结构, 以便进行光学吸收测量。在 77K 下观测到 SLS 的非线性光学吸收, 它只有当入射光波长和 SLS 的激子发射峰及吸收峰符合时才发生, 表明这种光学非线性与激子过程相关。

Two kinds of  $\text{ZnSe}/\text{ZnS}_x\text{Se}_{1-x}$  SLS structure on both transparent  $\text{CaF}_2(111)$  and  $\text{GaAs}(100)$  were grown and ascertained. The etched hole structure of  $\text{GaAs}$  substrate for SLS was successfully prepared for the first time, that allowed the optical absorption measurements can be carried on. The nonlinear absorption of SLS was observed at 77K only when the wavelength of incident laser agrees with that of excitonic emission and absorption. It proved that nonlinearity is related to exciton processes.

本文发表在《1989 光电子器件与集成技术年会论文集》

### **ZnTe 单晶薄膜和 ZnTe / ZnSe 应变超晶格的常压 MOCVD 法制备**

#### **Preparation of ZnTe Single Crystal Films and ZnTe / ZnSe Strained-Layer Superlattices by AP-MOCVD**

范广涵 江风益 宋世惠 范希武

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$\text{ZnSe-ZnTe}$  SLS 由于在可见光区域的光电器件的应用前景而受到重视。本文首次利用常压 MOCVD 方法, 在  $\text{GaAs}(100)$  衬底上用 DMZ、DETe 和  $\text{H}_2\text{Se}$  为源生长了高质量  $\text{ZnTe}$  单晶薄膜和  $\text{ZnTe-ZnSe}$  应变超晶格。用 X 射线衍射法和光荧光法表征了薄膜质量和超晶格结构, 吸收光峰中出现的四个吸收峰, 初步归结为  $\text{ZnSe}$  层电子阱  $\text{ZnTe}$  层空穴阱中  $n=1$  和 2 能级重轻空穴间的吸收。

$\text{ZnSe-ZnTe}$  SLS is attached much importance since its prospects for photoelectronic devices in visible light range. For the first time this paper reported the growth of high quality  $\text{ZnTe}$  single crystal epilayers and  $\text{ZnTe-ZnSe}$  SLS by AP-MOCVD using DMZ DETe and  $\text{H}_2\text{Se}$  as source materials. The high quality of  $\text{ZnTe}$  epilayers and the SLS structure were appraised by X-ray diffraction and photoluminescence. the four peaks in the absorption spectrum of SLS were tentatively attributed to the transition between heavy and light holes at  $n=1, 2$  subband levels.

本文发表在“全国化合物半导体和光电器件学术会议”，湖南大庸，1990 年

### 宽禁带 II-IV 族材料及其超晶格的 MOCVD 法生长及特性研究

#### Growth and Characterization of Wide-Gap II-IV Compounds and Their Superlattices Grown by MOCVD

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本文综述了作者数年来以常压 MOCVD 方法生长高质量 ZnSe、ZnS、ZnTe、 $\text{ZnS}_x\text{Se}_{1-x}$ 、 $\text{ZnS}_{1-x}\text{Te}_x$  单晶薄膜，ZnSe-ZnS、ZnSe-ZnSe $_{1-x}$ S $_{3-x}$ 、ZnSe-ZnTe 应变超晶格等 II-IV 族宽禁带材料；研究了这些材料的光电特性及生长条件对特性的影响。这些工作为 II-IV 族宽禁带材料用于短区域光发射受激发射及光学非线性器件准备了条件。

This paper summarized the preparations II-IV group wide gap materials(e.g. ZnSe, ZnS, ZnTe,  $\text{ZnS}_x\text{Se}_{1-x}$ ,  $\text{ZnS}_{1-x}\text{Te}_x$  single crystal films and ZnSe-ZnS, ZnSe-ZnS $_x$ Se $_{1-x}$ , ZnSe-ZnTe strained-layer superlattices) by AP-MOCVD in the last few years. The optical and electrical properties of these materials and the influences of growth conditions were investigated.

本文发表在“第一届全国 MOCVD 会议”

### 窄阱宽 ZnSe / ZnS SLS 的常压 MOCVD 法制备及鉴定

#### Preparation and Characterization of Narrow Well ZnSe-ZnS SLS by MOCVD at Atmospheric Pressure

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用微机控制常压 MOCVD 法，以 DMZ、 $\text{H}_2\text{S}$ 、 $\text{H}_2\text{Se}$  为源在 GaAs (100) 上生长了窄阱宽 ZnSe / ZnS SLS。反应器经特殊设计以避免 S 和 Se 在死空间的滞留及管道的吸附，以 X-射线衍射法和光荧光法鉴定了材料的超晶格结构，证实阱宽可达 1nm，也表明界面有好的陡度。

Narrow-Well ZnSe-ZnS Strained-Layer Superlattices were grown on GaAs(100) by atmospheric pressure MOCVD using DMZ, H<sub>2</sub>S and H<sub>2</sub>Se as sources. The reactor was specially designed to minimize the detention and absorption of S and Se in blind space and pipeline, X-ray diffraction and PL measurement ascertained the superlattice structure and indicated that minimum well width is only 1nm.

本文发表在“第一届全国 MOCVD 会议”

### ZnSe / ZnS 多量子阱激子光学双稳性 Excitonic Optical Bistability in ZnSe / ZnS Multiple Quantum Wells

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用有机金属化学汽相沉淀 (MOCVD) 法在 CaF<sub>2</sub> 衬底上生长的 ZnSe / ZnS 多量子阱材料, 其阱宽和垒宽皆为 5nm, 周期为 100。在 77K 下, 用 N<sub>2</sub> 激光器的 337.1nm 激光线泵浦的香豆素 440, 获得宽带蓝光脉冲, 进行了非线性光学测量。首次观察到 ZnSe / ZnS 多量子阱的激子光学双稳现象, 其开关时间为纳秒量级。根据我们获得的光学双稳回线的形状、发光和吸收光谱, 讨论了光双稳的机理, 并用激子带展宽的非线性理论计算结果与我们的实验结果进行比较。结果进一步表明, 我们在 ZnSe / ZnS 多量子阱材料上获得的光双稳是由于激子带展宽效应引起的增加吸收效应, 它比 ZnSe 体材料具有较低的开关能量阈值, 如在器件两面镀膜, 并实现器件设计的最佳化, 有可能提供一种新的实用光开关器件。

Optical bistability in ZnSe / ZnS multiple quantum wells (MQWs) grown by metalorganic chemical vapor deposition (MOCVD) on CaF<sub>2</sub> substrates has been observed in transmission at 77K with nanosecond (ns) switching time, for the first time. On the basis of the shape of hysteresis loop, photoluminescence (PL) and absorption spectra, we analyze the possible nonlinear mechanism for the optical bistability obtained here and compare the theory's optical bistability due to the effect of excitonic band broadening with our experimental result. The results indicate that the optical bistability in ZnSe / ZnS MQWs can be attributed to the enhanced absorption effect, which originated from the collision broadening of excitonic resonance.

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## 高失配度 $\text{ZnSe}_{1-x}\text{S}_x\text{-ZnSe}$ 应变超晶格结构的 应力分析和结构参数的计算

### High Mismatch $\text{ZnSe}_{1-x}\text{S}_x\text{-ZnSe}$ SLS' Interfacial Strain and Structure Parameter

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本文根据超晶格结构的台阶模型, 利用 X-衍射的实验数据及二维面应力导致晶格的四方畸变的关系式, 分析了高失配度 ( $X=1$  时,  $f=4.7\%$ ) 的  $\text{ZnSe}_{1-x}\text{S}_x\text{-ZnSe}$  应变超晶格结构的界面应力效应, 给出了计算  $\text{ZnSe}_{1-x}\text{S}_x\text{-ZnSe}$  超晶格结构参数的计算公式。仅由“零级峰”的角位置和超晶格卫星峰之间的角距离, 通过联合方程组可求出该结构的结构参数及势阱和势垒层厚度  $L_1L_2$ 。

In this paper, we discuss the interfacial strain in high mismatch(4.7%) $\text{ZnSe}_{1-x}\text{S}_x\text{-ZnSe}$  SLS by elastic strain theory and angle positive of satellite peaks in X-ray diffraction pattern. We obtain the calculaing formula on SLS' structural parameters.

In SLS structure the lattice parameter  $a''$ , parallel to the substrate plane, is different from the lattice constant of the substrate or the buffer layer. A compressive strain( $e''_{\text{ZnS}}$ ) is introduced in ZnSe layer, while a tensile strain( $e''_{\text{ZnS}}$ ) acts in ZnS layer. On the other hand, the lattice parameters normal to the wafer surface are related to  $a''$ . From the X-ray measurment of (400) diffraction we can get the SLS' period  $D$  and "zero-order diffraction" angle  $\theta_0$ , then solve every parameter .

本文发表在《固体电子学研究进展》, 第9卷, 1989年

## ZnZe 薄膜瞬态光学非线性测量

### The Transient Optical Nonlinearity in ZnSe Thin Film

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我们用单光束方法, 以 Boxcar 信号平均器对纳秒量级光脉冲信号进行取样积分, 实现了对 ZnZe 的光学非线性测量。用氮分子激光器泵浦激光染料香豆素 440, 获得全波段输出半宽度约为 8nm 的窄带超荧光脉冲, 重复频率 20Hz, 平均功率 7mW。将样品置于液氮中, 使超荧光通过样品, 经单色仪分光后, 由光电倍增管、Boxcar 和打印机给出瞬态透射光谱, 发现样品吸收在 437nm 有明显非线性变化。以透射单脉冲和入射单脉冲作光强变化关系曲线, 得到了光学双稳回线。这种纳秒量级光学非线性是由于激子吸收增强、漂白和屏蔽效应造成的。

The optical nonlinearity of ZnSe thin film was measured by single light beam method. The superfluorescence emitted by a cell containing coumarin 440 was used to determine the changes in the absorption coefficient as a function of the excitation intensity and the wavelength. The dye cell was pumped a nitrogen laser(337.1nm) with 10ns FWHM of 20Hz. The average output power is 7mw. The peak position of optical nonlinear absorption in ZnSe thin film at 77K locates at 437nm. The transmission spectrum as a function of the incident light density shows a bistability loop. The optical nonlinear mechanism of ZnSe thin film can be attributed to the increasing absorption and the bleaching of excitons.

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### 高激发密度下 ZnSe-ZnS

#### 应变超晶格的发光

#### Photoluminescence of ZnSe-ZnS STRAINED-LAYER

#### Superlattice Under High Excitations

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· 研究了 ZnSe-ZnS 超晶格在 77~250K 范围内发光峰  $E_s$  的起因，把它归结为自由激子受电子的散射发光。首次指出了在高密度激发下 ZnSe-ZnS 超晶格的发光峰  $E_s$  内包含四种类型的激子散射，并给出了相应的散射强度；利用势阱中激子束缚能的增大，解释了难以观察到 ZnSe-ZnS 中分离的 P 带的原因。

The luminescence spectra of high density excitons in a ZnSe-ZnS strained-layer superlattice(SLS) have been studied in the temperature range 77-250K. The photoluminescence(PL) spectrum in the SLS usually has only one near edge emission band  $E_e$ . The  $E_e$  band is attributed to free exciton recombination following scattering from electrons in the conduction band. According to whether the binding energy of the free exciton increases as the well width of SLS decreases, it can be explained why it is difficult to observe the separated P band in ZnSe-ZnS SLS system.

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### VPE 生长 CdS 外延膜的光学性质与光学双稳态

#### Optical Property and Bistability of CdS Epilayers Phase Epitaxy



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用气相外延法在  $\text{CaF}_2$ -(111)衬底上生长 CdS 薄膜。在 77K 用  $\text{N}_2$  激光器的 337.1nm 线激发 CdS 薄膜的光致发光 (PL) 489nm, 产生一个起源于束缚在中性施主上的激子发射带, 主导整个光谱, 并一直延续到室温成为 519nm 发射带。其他像自由激子发射和施主-受主对发射以及深中心发射都很弱。CdS 薄膜的光吸收 77K 下在 487nm, 室温下延续到 510nm 附近, 吸收边也都很陡峭。

室温下用  $\text{Ar}^+$  激光器 514nm 线经斩波器调制成 6ms 的光脉冲, 在 20mW 功率下, 照射 8 $\mu\text{m}$  厚的 CdS 膜的一侧, 用两个光电二极管同时检测入射和透射光的波形。透过 CdS 膜后的光脉冲波形在其前沿和后沿都出现了尖峰, 呈现出典型的增加吸收型光双稳特征。其机理是, 光脉冲入射 CdS 中, 由于光吸收使晶体温度升高。CdS 的带隙变窄, 吸收边红移, 使晶体吸收增加。测得入射光从高透过跌到低透过所需的开关时间为 200 $\mu\text{s}$ 。

Optical bistability (OB) in semiconductors is of increasing interest in both basic and applied research. Much is known about optical nonlinearities and OB in CdS crystals. This paper reports, for the first time, about the optical bistability in CdS single crystal films grown on  $\text{CaF}_2$  transparent substrate. High quality of the film has been identified by photoluminescence and absorption. The OB is measured by 514.5nm line of  $\text{Ar}^+$  Laser modulated into 6ms square light pulses at room temperature. Two peaks appear at the front and back edges of transmitted light pulses. The switching time is about 200 $\mu\text{s}$  at 20mW power level, which is CdS bulk crystal at the same condition. The mechanism of the OB is due to increasing absorption and thermal red shift of the absorption edge.

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### **ZnSe-ZnS / GaAs 多量子阱的色散光双稳**

Dispersive Optical Bistability in

ZnSe-ZnS / GaAs Multiple Quantum Wells

申德振 范希武 范广涵 张吉英

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用有机金属化学气相沉积法, 在 GaAs 衬底上的 ZnSe-ZnS 多量子阱用  $\text{N}_2$  激光器的 337.1nm 脉冲激光泵浦香豆素 440 染料对获得的宽带脉冲光进行了非线性测量。首次在 77K 下具有腐蚀孔的 ZnSe-ZnS / GaAs 多量子阱上观察到具有不同回线方向的光双稳现象, 开关时间为纳秒量级。根据获得的光双稳回线的性质, 激子的吸收和发光谱, 讨论了光双稳的物理机制。用 F-P 腔的理论和激子饱和吸收特性, 分析了不同光双稳回线方向

的起因。结果表明, 在 ZnSe-ZnS / GaAs 多量子阱上获得的光双稳是色散型的, 正反馈机制是由于 ZnSe-ZnS 多量子阱两表面形成一个简单的 F-P 腔, 主要非线性机理是激子的饱和吸收效应引起的折射率变化。该结果受到国际同行的重视。

Optical bistability which have different direction of hysteresis Loops in ZnSe-ZnS / GaAs MQWs with etching hole on GaAs substrates have been observed in transmission at 77K with nanosecond (ns) switching time, for the first time. On the basis of the shape of hysteresis Loops, photoluminescence (PL) and absorption spectra measured, we have discussed the possible nonlinear mechanism for the optical bistability obtained here and analyzed the major contribution to the nonlinearity in accordance with the F-P cavity's theory and nature of excitonic saturating absorption. The results indicate that the optical bistability obtained here is dispersive and its origin is due to the change of refractive index caused by the effect of excitonic saturating absorption.

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## ZnSe—ZnS 应变层超晶格中 D—A 对发光

### D—A Pair Luminescence

#### in ZnSe—ZnS Strained Layer Superlattice

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在 77K 温度的 ZnSe-ZnS /  $\text{CaF}_2$  应变超晶格的低密度激发下, 得到了峰值在 440nm ( $E_{1hh}$  和 449nm(DAP)的两个发光带。随着激发密度增加, 发现 DAP 带移向高能边; 最终, DAP 带与  $E_{1hh}$  带混合在一起。混合带的峰值位置为 442nm (M)。在不同激发密度下, M 带的时间分辨光谱随着时间的延迟逐渐移向低能边。这是施主—受主对复合发光的典型特征。在室温, M 带的发光与 77K 时具有同一特征。根据吸收光谱和晶体中的应变理论, 证明  $E_{1hh}$  带起源于  $n=1$  重空穴激子复合。M 带的绝大部分, 可归结为超晶格生长过程中引进的施主杂质与起受主作用的悬键的复合。

Two luminescent bands peaked at 440nm ( $E_{1hh}$ ) and 449nm (DAP) separately in ZnSe-ZnS /  $\text{CaF}_2$  Strained-Layer Superlattices were shown under lower excitation density at 77K. With increasing excitation density it was found that the DAP band shifts towards the higher energy side, finally, the DAP band mixed with  $E_{1hh}$  whose peak position is at 442nm(M). The time — resolved spectrum of M band under different excitation density shifts gradually towards the lower energy side with increasing time decay. This is a typical characteristic related to the photoluminescence of the donor—acceptor recombination. The

M band at RT shows the same features as that at 77K during increasing decay and with increasing excitation density.

From the fact that the photoluminescence spectra from 77K to RT shift towards lower energy with increasing temperature, it can not come from the self-activated luminescence. According to the absorption spectra, Kronig-Penny model and stress theory in crystal  $E_{hh}$  band originates from  $n=1$  heavy hole exciton recombination.

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### **O<sup>+</sup>注入 InP 的实验研究**

#### **Experimental Investigation on O<sup>+</sup> Implantation of InP**

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利用本所离子注入机首次开展了 O<sup>+</sup>注入 InP 的实验研究工作，文中将介绍主要实验结果，其中包括：

- (1)关于 O<sup>+</sup>注入深度与注入能量的关系；
- (2)关于某些常规材料(AZ1350J光刻胶、Au膜、Cr/Au复合膜、SiO<sub>2</sub>、PSG等)对O<sup>+</sup>注入的掩蔽特性的研究；
- (3)关于 O<sup>+</sup>注入技术在 InP / InGaAsP 双稳激光器制备中的应用的研究等。

The experimental investigation on O<sup>+</sup> implantation of InP for the first time has been made in a home-made ion implanting system. In this paper, the following results will be introduced:

- (1)The dependence of the implanted depth on energy;
- (2)The masking capability of some material including photoresist AZ1350J, Au film evaporated, Cr / Au complex film, SiO<sub>2</sub> and PSG; and
- (3)The some application in fabrication of the InP / InGaAsP CCTS optical bistable lasers.

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### **InP 材料 UV 激光直接刻蚀研究**

#### **Investigation of UV Laser Direct Etching on InP Material**

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(吉林大学)

利用 UV 激光的光解剥离 (APD) 效应, 对半导体材料 In 进行了直接刻蚀研究, 获得了良好的结果。采用波长为 308nm, 光脉冲宽度 20ns 的 XeCl 准分子激光器, APD 刻蚀的光能密度阈值为  $390\text{mJ}/\text{cm}^2$ ; 与理论结果相比较, 两者具有良好的一致性。同时给出了刻蚀深度与脉冲速率及脉冲时间的实验曲线。

An investigation of direct etching on semiconductor InP by UV laser APD effect has been made and a good result was achieved. The experimental APD fluency threshold is about  $390\text{mJ}/\text{cm}^2$  by an XeCl excimer laser with a wavelength of 308nm and a pulse width of 20ns. + Compared with the theoretical results, they are coincident well with each other. Experimental curves of etching depth versus repeated rate and radiation time of laser pulse are given.

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### 准分子激光直接刻蚀 InP 半导体材料

#### Etching of Semiconductor InP by Direct Excimer Laser

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(吉林大学)

本文首次报告了利用准分子激光的 APD 效应直接刻蚀半导体材料 InP。研究结果表明, 与高分子聚合物的 APD 刻蚀相似, InP 材料的 APD 刻蚀也存在一个能量密度阈值, 并直接影响其刻蚀质量。

Etching of semiconductor InP by the ablative photodecomposition (APD) of direct excimer laser was achieved successfully for the first. It was also confirmed that the laser fluence exists a threshold analogous to polymer in APD process and influences the etching quality directly.

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### 晶体 APD 断键弛豫的经典讨论

#### Ablative Photodecomposition of Crystals: Classical Discussion

#### About Bond Breaking Relaxation

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(吉林大学)

紫外激光辐照晶体将引起材料的光解剥离 (APD)。这一剥离过程存在一个入射光能量密度阈值。当光波长给定时, 该阈值与材料参数及断键动力学过程有关。本文依据具有 fcc 结构的晶体结合的经典理论提出一个断键弛豫模型, 阐明了断键弛豫时间与入射光子能量, 材料参数之间的关系, 一定程度上解释了光解剥离过程。

Irradiation of UV laser may cause ablative photodecomposition (APD). A fluence threshold exists in this process. Given laser wavelength, the threshold is related to the material parameters and dynamics of bond breaking. In this paper, a model of bond breaking relaxation which bases on a classical theory of fcc crystal combination is proposed. This model accounts for the relationship among the relaxation time of bond breaking, the energy of an incident photon and the material parameters. The APD process has been explained under some extent.

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### 准分子激光刻蚀金属薄膜的边缘质量研究

#### A Study for Edge Quality of Excimer Laser Etching Metal Thin Film

郑晓风 张庆有 张玉书

(吉林大学)

本文通过求解横向一维热传导方程, 半定量地研究了准分子激光刻蚀金属薄膜的边缘质量。样品采用在半导体材料衬底上蒸发而成厚约 100nm 的锌膜, 激光器的工作波长为 308nm。研究表明: 在同一能量密度下, 激光脉宽越短, 刻蚀边缘质量越好; 而在同一激光脉宽时, 激光能量密度越大, 刻蚀边缘质量越好; 当刻蚀的条宽足够大时, 刻蚀边缘质量与条宽无关。

This paper reports a semi quatative study for edge quality of excimer laser etching metal thin film by means of solving a one dimension thermal conduction equation. The sample used is the 100nm thick Zn film deposited on semiconductor substrate and the laser wavelength is 308nm. It shows that for the same laser fluence, the shorter pulse width, the better edge quality; and for the same laser pulse width, the bigger laser fluence, the better edge quality; and if etching stripe width is large enough, edge quality has nothing to do with it.

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报》，1990 年特刊

## 离子交换引起的折射率与体积变化

### The Refraction and Volume Variation Caused by Ion-Exchange

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离子交换引起介质性质的变化情况是微小光学器件中的一个重要问题。本文分析了玻璃的折射率和体积与其化学成份间的依赖关系，以此为基础导出了离子交换所引起的玻璃折射率和体积改变与替换离子间的关系，给出了计算实例。计算表明对于  $\text{Ti}^+ - \text{Na}^+$ ，不仅交换区折射率增大，体积也变大因而向外凸起，这些都已为我们的实验所证实。

The refraction and volume variation caused by ion exchange is a important problem in micro optical devices. From the fact that the glass refraction and volume was related with its chemical compositions, we derived the relationship of the glase refraction and volume variation caused by ion exchange with the exchanged ions, and gave a calculation example. The calculation showed that, in the case of  $\text{Ti}^+ - \text{Na}^+$  exchanging, the glass refraction and volume were all increased, hence the area exchanged humped up. These had been demonstrated by our experiments.

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## 平面微透镜阵列用于波前的自动检测

### Automatical Wavefront Detection Using Planar Micro-Lens Array

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本文提出了一种应用平面微透镜阵列进行波前自动检测的系统结构，它包括一块平面微透镜阵列，一个 CCD 相机及处理设备。文章分析了在现有条件下可以达到的精度，并指出其具有光效率高，结构简单可靠，可适用于白光以及采样区相位差可超过  $2\pi$  等优点。

A system structure for automatical wavefront detection using a planar microlens array, a CCD camera and a process system was proposed in this paper. The precision that might be get under present condition was also discussed. Part of the advantadges of the system was pointed out, they were high light energe efficiency, simple structure, could be

used in white light and the phase difference could be over  $2\pi$ .

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### 用顶覆层法在 YIG / GGG 磁光波导上制作平面波导透镜

#### Fabricate the Plane Wave-Guide Lens on YIG / GGG Magneto-optical Wave-Guide by Top Layer

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由于 YIG / GGG 磁光波导本身结构及性能的特殊性,使得以往用于声光频谱分析仪器的各种平面波导透镜方法在用于 YIG / GGG 波导结构时会在工艺上带来许多难以克服的困难。我们提出一种新的平面波导透镜结构,即用高折射率的顶覆层来影响波导的有效折射率,并制定了相应的工艺路线。这种透镜的结构简单,制作方便并很容易推广到其他的波导元件上,特别适合于集成光系统的制作,我们用  $\alpha$ -Si : H 覆层在 YIG / GGG 波导上制作的透镜,其结果是令人满意的。

We suppose a new kinds of structure about plane wave-guide lens, i.e. effective index will be influenced by high index cover layer, and new way to fabricate it. Compare with other coverage lens, the lens of new structure has some advantage such as structure is very simple, and fabrication is very easy. And this method can be used widely in IO system. We made a lens on YIG / GGG wave-guide by  $\alpha$ -Si : H coverage. Testing result is good.

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### 集成光学声光频谱分析仪中光学信号的数据采集与处理

#### Data Sampling and Processing Technique of Optical Signals in IOSA

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本文报导了对集成光学声光频谱分析仪中光学信号的数据采集与处理的研究。CCD 器件用作光电转换器,以 IBM—PC 和 TMS32010 高速信号处理器用作信号处理中心。

This paper has introduced our study for the data sampling and processing of optical signals in IOSA. The CCD device is used as the optic-electric transformer, and the IBM—PC and TMS32010 fast signal processor is used as the signal processing center.

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### 非球面短程透镜的焦点特性

#### Focus Properties of Aspheric Geodesic Lenses

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报导了非球面波导短程透镜的实验测量结果。测量是用 CCD 器件进行的。对于束腰半径为 0.75mm 的输入高斯光束, 在焦点处测得的光斑束腰最小半径为  $5\mu\text{m}$ , 此值接近理论值  $3.8\mu\text{m}$ 。

The experimental measurements of the focus spot properties of the aspheric geodesic lenses are reported. The experiment is carried out by CCD devices. The minimum beam radius at the lens focus is  $5\mu\text{m}$  when the beam radius of the input Gaussian beam of 0.75mm. This value closes to the theoretical value of  $3.8\mu\text{m}$ .

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### 短程透镜设计方法的比较

#### A Comparison of Design Method for Geodesic Lenses

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通过实际计算, 对设计波导短程透镜的两种方法进行了比较。结果表明, 精确法较迭代法有精度高和计算时间短的优点, 但精确法得到的透镜边缘性能较差。

A comparison of two methods for design waveguide geodesic lenses has been done. It is shown through practical computing that the exact method has both advantages of short compute period and of high precision. But the lens edge computed by exact method is poor.

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### 体全息光栅平均介电常数和电导率的变化对其衍射效率的影响



## Effects of the Change in Average Permittivity and Conductivity of Volume Hologram Grating on its Diffraction Efficiency

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本文研究了一种新的描述光波在全息光栅内传播模型。讨论了由于体全息光栅平均介电常数和电导率的变化对体全息光栅衍射效率的影响。并将这些结果与 Solymar 获得的结果进行了比较。最后指出这种变化对光栅效率产生的影响可以进行补偿。

A method describing the propagation of optical waves in a hologram volume grating is studied. Then the effects of change in the average permittivity and conductivity of a grating on diffraction efficiency are discussed. Finally, a comparison of the results this model with those by Solymar is made. The authors come to a conclusion that the effects of the changes can be compensated.

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